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ARC AND GLOW LAMPS.

THE SPECIALISTS' SERIES.

ARC AND GLOW LAMPS.

A PRACTICAL HANDBOOK

ON

ELECTRIC LIGHTING.

BY

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LONDON:
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PREFACE.

The subject of Electric Lighting is daily becoming of greater importance, and the present book is intended to give an account of the methods and apparatus used for electric lighting up to this date. For this purpose, the results of the official tests made at the Electrical Exhibitions of Paris, Munich, Vienna and Philadelphia, and also of the London Health Exhibition, have been incorporated, and the latest improvements in the manufacture of arc and glow lamps, and also in the mode of installation of these lamps have been carefully registered in this book.

Merling's book on Electric Lighting has been extensively followed, and the greater part of the illustrations have been taken from it.

I have to thank the Brush Company and Messrs. Ganz & Co. of Buda-Pest for kindly supplying me with blocks illustrating their systems, and also, "last but not least," my esteemed friend, Mr. W. H. Preece, for the important assistance he has rendered me in reading the proofs and making many valuable alterations and additions which, I am sure, will contribute in no small degree in enhancing the usefulness of this book.

London, *July*, 1886.

CONTENTS.

PAGE
INTRODUCTION 1

PART I.

ELECTRIC LIGHT.

PAR.
1. DIFFERENCE BETWEEN ARC AND GLOW LIGHT 6
2. GENERATION OF HEAT AND LIGHT BY THE ELECTRIC CURRENT (JOULE'S AND OHM'S LAWS) 7
3. ELECTRICAL UNITS AND THEIR RELATION TO UNITS OF WORK 11
4. DISTRIBUTION OF HEAT IN AN ELECTRIC CIRCUIT 15
5. EFFICIENCY OF DYNAMOS, AND THEIR APPLICATION TO ELECTRIC LIGHTING 28
6. ELECTRIC MEASUREMENTS 52
7. PHOTOMETRIC METHODS 77
8. ARRANGEMENT OF LEADS AND LAMPS. INSTALLATIONS .. 83

PART II.

ARC LAMPS.

1. PREPARATION OF CARBONS FOR ARC LAMPS 147
2. INTENSITY OF THE ARC AND DIRECTION OF LIGHT-RAYS .. 153
3. MONOPHOTAL OR SINGLE-LIGHT ARC LAMPS 164
4. POLYPHOTAL LAMPS 185
5. GENERAL REMARKS ON THE CONSTRUCTION OF ARC LAMPS .. 232
6. ARC LAMPS WITH OBLIQUE CARBONS 245
7. ELECTRIC CANDLES 250

PART III.

GLOW LAMPS.

PAR. PAGE
1. Lamps combining incandescence and combustion .. 263
2. Lamps purely incandescent 269
3. General remarks on the construction, efficiency, and life of glow lamps 301

PART IV.

THE APPLICATIONS OF ELECTRIC LIGHTING.

Secondary batteries 330
Dynamos 337
1. Illumination of lighthouses 347
2. Ship lighting 349
3. Night signalling 354
4. Electric light in collieries 355
5. Application to military operations 358
6. Illumination of railway trains 359
7. Illumination of theatres 262
8. Electric light applied to photography 365
9. Electric light applied to the microscope 366
10. Application of electric light to surgical operations 368

ELECTRIC LIGHTING.

INTRODUCTION.

THE industrial progress as well as the progress in science —the most characteristic features of the present century —are clearly discernible in the advance which lighting has made within the last fifty years. Would not horror seize us had we to go back from the elegant Swan lamp, or even the gas burner, to the blessed penny-dip! And it is not our æsthetic feelings alone which would be outraged; such a retrograde step would have the most momentous consequences. What would become of the traffic in the London streets, what of our mills, our factories, and our shops?

In the same measure as industrial and scientific progress show themselves in the vast improvement of our methods for illumination, so is this improvement essential, indispensable, for the advance of civilisation, of culture, and of material comfort.

It is difficult to realize the fact that ninety years ago the tallow candle and the oil lamp were the only available lighting apparatus, and also difficult to conceive how our forefathers could content themselves with such meagre and insufficient appliances. We easily understand the enthusiasm provoked by the first introduction of a central lighting system—namely, gas. Requirements increase with increased facilities for satisfying them. What kindled enthusiasm in 1814, when gas was first used for lighting the London streets, would provoke—to say the least—hostile criticism nowadays, and would certainly give rise to no small amount of confusion and inconvenience.

Years elapsed before gas made its way from the street to the dwelling-house—years marked by the collapse of many gas companies. Well, we can only say on that head, "History repeats itself." Read electric light instead of gas, and we have the present state of affairs, and we are justified in predicting the same final issue for the most recent improvement in lighting—the electric light.

PART I.

ELECTRIC LIGHT.

THE great advantages of gas, its cheapness, its distribution, and the all but absolute safety of its working, secured for it, and rightly so, a monopoly extending over more than half a century, and we need not be surprised that a new system of lighting has not been, and will not be, generally adopted until it has conclusively proved its superiority over the methods in use at the present time. The question whether electricity has done this may be answered in the affirmative. It has proved its superiority over gas in every point except as regards its price. Its distribution is practically unlimited, like that of gas, whilst in its working it affords even greater security than its older competitor. The only danger in the use of electricity is that through an incomplete insulation of the conductors, the powerful currents required for the production of electric light might set fire to inflammable material in close proximity to the faulty part of the conducting wire. Careful insulation will reduce this risk to a minimum, while in the case of gas it will never be eliminated, depending as it does upon the amount of care employed by the consumer.

There is little to choose between the two systems as regards simplicity and security, but when we look at the question from a sanitary point of view, we find that, to use a common expression, "Gas is not in it;" electricity has it all its own way. The immense superiority of electric light in this respect will easily follow from the consideration of two points. In the first instance we find that the heat produced by the voltaic arc is very intense, but exceedingly small in quantity. For an equal amount of light a gas burner produces about 100 times more heat than the voltaic arc. Further, 94 per cent. of our common coal gas are, in the process of combustion, transmuted into heat, while only 6 per cent. are available for the production of light. Secondly, the electric light deprives the air of a very small quantity of oxygen (the glow lamp requires none at all) and does not produce any noxious gases like carbonic acid, sulphur dioxide and others, which mingle with the atmosphere and vitiate it, to the detriment of our health and comfort. The following table* will clearly show the superiority of electric light with regard to the two points mentioned.

A Light of 100 Candles per hour

Requires		Produces		
System of Lighting.	Quantity.	Water. Kilogr.	Carbonic acid cbm. at 0°.	Calories.
Electric arc light . .	·09–·25 H.P.	0	0	57–158
Electric glow light .	·46–·85 H.P.	0	0	290–536
Siemens' gas lamp .	·35–·56 cbm.	—	—	1,500
Argand gas burner .	·8–2 cbm.	·86	·46	4,860
Ordinary gas burner .	2 cbm.–8 cbm.	2·14	1·14	12,150
Paraffin lamp . . .	·77 klgr.	·99	1·22	9,200
Colza oil lamp. . .	·43 klgr.	·52	·61	4,200

Further advantages of electric light are its quality, which permits the distinction of the most delicate shades of colour, its entire freedom of smell, and its non-explosive properties.

---

* Dr. Ferd. Fischer, Dingler's *Polytechnisches Journal*, 248, 375, 1883.

The only objection to electric lighting, the only reason why it has not yet been generally adopted for domestic purposes, is its expensiveness. If our gas companies had not exceptional privileges accorded to them by law, if they could be compelled by competition to supply gas at a price which would give them a reasonable profit only, we should have gas at one fifth of its present price. It is well known that the by-products, tar, ammoniacal liquors and coke, pay for the whole manufacturing process and leave gas a clear profit to the companies. It will therefore easily be seen that as long as electric light cannot even compete with the present price of gas its general introduction for domestic purposes is out of the question. Now, it is not the cost of the lighting apparatus which makes electric light expensive, it is the complicated nature of the apparatus required for generating powerful electric currents, such as are required for lighting purposes. We may safely say that as long as dynamos, steam or gas engines, accumulators, primary batteries in their present form, are employed for generating electricity, gas will maintain its monopoly, people's eyesight will suffer, their blood will be poisoned, their existence during a considerable portion of their lives will be rendered miserable by our present methods of lighting.

A general adoption of electric light for domestic purposes would in any case only be possible by the establishment of central stations, such as we see them in New York and a few other cities of the United States. The reason why such central stations can there be successfully worked is not far to seek. Gas is much dearer in America, and electric light compares favourably with it as far as expense is concerned.

All these considerations apply only to the general use of electric light in private houses; in all localities where a large number of lights are required, such as theatres, clubs, shops and warehouses, factories, railway stations, public offices, large hotels, etc., separate electric installations will be found advantageous in every respect—a fact which is gradually being acknowledged all round, and which is proved by the numerous installations coming into existence almost daily.

§ 1. DIFFERENCE BETWEEN ARC AND GLOW LIGHT.

The practical form which electric light has assumed is known under the names of arc light and glow light.

The difference between these two systems lies in the way in which the light is produced. In the glow lamp we have a closed circuit, a solid conductor in the shape of a metal wire, or more frequently a carbon filament, heated to white heat by the passing current. The filament is enclosed in a vacuum, and is thereby protected from combustion. In the arc lamp the current passes between two carbons which are at a short distance from each other and are gradually consumed in the air. The passage of the current is continued through the heated air, which is a moderate conductor of high resistance; small particles of carbon are detached from the two carbon electrodes, are heated in the air between, form a luminous "arc," and thereby add to the light. With the gradual consumption of the carbon points the distance between them increases and the passage of the current would become impossible without some suitable mechanical contrivance for pushing them forward.

This constitutes a serious difficulty in working a number of arc lamps in the same circuit, a difficulty which does not present itself in the case of the glow lamp. Each of the two systems, however, has its own peculiar advantages: the arc light is specially fitted in cases where large quantities of light are required, as for lighting of streets, large public squares, railway stations, lighthouses, and also when delicate tints of colour have to be accurately distinguished. It has the further advantage of cheapness over the glow lamp wherever an intense light is wanted emanating from one centre.

The advantages of the glow light are its easy distribution, which to all intents and purposes is unlimited, and the steady character of the light, for which latter quality it favourably compares with arc and gas light. It produces no perceptible amount of heat, and is therefore eminently fitted for lighting the interior of dwelling-houses, theatres, reading-rooms, in short all such localities where a steady, brilliant, and wholesome light will be found to contribute in no small degree to the comforts of our existence.

§ 2. GENERATION OF HEAT AND LIGHT BY THE ELECTRIC CURRENT (JOULE'S AND OHM'S LAWS).

The light effect of a flame is dependent upon a certain temperature; if the light, therefore, is to be produced by the electric current, a generation of heat must necessarily precede it. The sparks produced on breaking the closed circuit of a galvanic battery, as well as the sparks obtained from an electric friction machine, and also lightning, are effects of electric light. The sparks obtained from a galvanic battery have a temperature sufficiently high to melt, in some instances even to burn, the ends of the metallic conductors between which they pass. The requisite heat for the formation of these sparks is supplied by the electric current. This latter is entirely transmuted into heat, in so far as it does no other work, as for instance magnetise iron or give rise to chemical or mechanical effects. The relation between the generation of heat and light within a closed circuit are only known as far as they can be disclosed by experiment. We know in a general way that the conditions which influence the generation of heat also determine within certain limits the generation of light.

We have, therefore, in the first place to consider the heating effects of the electric current. According to Joule's law the work W done in the generation of heat during unit of time (one second) is

$$W = C^2R \quad . \quad . \quad . \quad . \quad . \quad (1)$$

or in words, W is equal to the product of the square of the current C and the resistance R of the circuit. We know from Ohm's law that

$$C = \frac{E}{R}$$

where E is the electromotive force in volts, R resistance in ohms and C current in ampères. By substituting these values in the above equation we get

$$W = \frac{E^2}{R} = EC \quad . \quad . \quad . \quad . \quad . \quad (2)$$

In order to obtain effects of incandescence the heat generated must be as far as possible concentrated upon the incandescent area; any rise of temperature in the remainder of the circuit means a loss of work. Joule's law teaches us how to obtain these effects under the most favourable conditions.

Equation $W = C^2R$ tells us that in circuits of equal current C, the heat generated (assuming the heat to be equal to the whole amount W of work produced) is proportional to the resistance R, and in circuits of equal resistance R proportional to the square of the current C.

Equation $W = \frac{E^2}{R}$ signifies that in circuits of equal electromotive force E (that is to say emanating from the same constant electric source) the heat W generated is in inverse proportion to the resistance R, and in a circuit of the same resistance in direct proportion to the square of the electromotive force E.

Equation $W = EC$ shows that in circuits of equal current, equal electric source and different resistance, the heat generated is in direct proportion to the electromotive force E and the current C.

On considering the conditions of the same circuit we learn from Ohm's law that the current C being the quotient of the electromotive force E of the battery (or in other words of the electric source), and the *total* resistance R of the circuit *being the same in all parts of this latter*, therefore, according to the equation $W = C^2R$, the heat generated in any individual part of the circuit entirely depends on the resistance of this part, and increases with that resistance. If, therefore, the circuit shows the *same* resistance in all its parts, either through the employment of the same material of equal section (wire of the same size), or by using different materials of different sections but corresponding conductivity * (wires of different size), the heat will be generated uniformly in all parts of the circuit. And if this circuit consists of copper, that is to say, that material of all others which amongst the practically available metals has the highest conductivity, we obtain by employing the thickest and shortest possible wires (or in other words, by reducing the resistance to the lowest possible minimum) the strongest possible current obtainable from an electric source. The effects of this current will now, according to Joule's law, preponderate over the effects of the resistance in the conductor. If we now interpolate in the circuit a short and very fine wire of moderate conductivity * (platinum, German silver, carbon, etc.), that is to say, a conductor of high resistance, the largest amount of heat will be generated in this latter part. The rise of temperature in the conductor, however, is not an absolute measure of the heat generated, for we have to take into consideration the absorption and emission of heat, either by direct conduction to the neighbouring objects, or by radiation, or by a combined simultaneous effect. A stout conductor absorbs more heat than a thin one, but the latter has in proportion to its section a larger surface which gives off more heat to the neighbouring objects, and thereby counteracts the effects of heating. It will be easily seen from this that a flat-shaped conductor, a flat wire, is on account of its larger surface more exposed to the effects of cooling than a cylindrical one, and that this latter is therefore with advantage used for producing incandescence at a given spot, while the former ought to be employed in those parts of the circuit where heating is to be avoided. To obtain incandescence the locality in question ought to be

---

* The conductivity is directly, and the resistance inversely, proportional to the section of the conductor.

---

* On putting the specific resistance of copper = 1, we get for iron = 5·35, platinum = 6·44, German silver = 11·54, mercury = 50, and carbon = 3000 at the average temperature of the atmosphere.

protected from all cooling influences, while for the remaining parts of the solid conductor cooling is the more desirable, as its resistance * is thereby diminished and, according to Ohm's law, the current strength in the circuit increased.

The degree of heating is further dependent upon the specific heat of the conductor, the less its specific heat the higher its temperature. According to this the expenditure of heat is also the greater the higher the specific heat of the neighbourhood of the conductor.

§ 3. ELECTRICAL UNITS AND THEIR RELATION TO UNITS OF WORK.

Electromotive Force.

A certain pressure or potential is required to force an electric current through a wire, in the same way as water will not flow through a pipe without pressure. This pressure—electromotive force, as it is called in our case—is supplied by some sort of generator, and on it depends—a conducting circuit being available—the quantity of the electric flow, in the same way as the quantity of the flow of water through a pipe depends on the pressure employed. The quantity of water discharged is analogous to the strength of current, or as we generally say to *the current;* and head of water, or the pressure by which this discharge is effected, is analogous to the *electromotive* force. The product of both represents in either case the effects of the flow, that is *the work* done by the current. The unit of electromotive force is called the *volt*, and an electromotive force of one volt is nearly equal to the difference of electrical pressure (difference of potential) between the two pole-ends of a Daniell's cell.

---

* The resistance of solid conductors, with the exception of carbon, increases with the increase of temperature; the colder the conductor the greater its conductivity. For pure metals the increase of resistance is generally ·0004 per degree centigrade; at a very high temperature the increase is larger.

Resistance.

Whenever we employ conductors of any kind in order to produce effects at a distance from the generating force we must take into consideration a loss of force in these conductors. The loss is generally occasioned by friction, as for instance by the friction of the flowing water against the sides of the conducting pipe. Again, in the case of gas we find a diminution of pressure the further we get away from the gas works. In the same way we find conductors of every kind offering a certain specific *resistance* to the electric flow. It does not signify for our purposes whether we consider an electric current as a transference of the luminiferous "*ether*" through a conducting material or as a peculiar kind of motion of the molecules of the conductor itself, the fact remains the same, namely, that the rate of motion varies exceedingly in different bodies: that certain substances, like metals, offer a slight resistance, and some other substances, like wood, glass, etc., a very considerable resistance to the electric flow. We therefore speak of metals, carbon, etc., as "conductors," and glass, wood, india-rubber, etc., as "non-conductors," although this latter application is not correct, no substance being an absolute non-conductor of electricity, any more than of heat. The laws of electrical resistance, as has been stated on p. 9, are extremely simple: *The resistance is proportional to the length and in inverse proportion to the cross section of the conductor.* The unit of resistance is called the *Ohm*, and its value was fixed in 1862, by a committee of the British Association, as equal to the resistance of a column of mercury of 104 centimetres in length and 1 square millimetre section. This value has been altered quite lately by a congress which met in Paris in 1884. The present value is the resistance of a column of mercury of 106 cms. length and 1 square millimetre section, and is called the legal ohm.

Current.

Electromotive force and resistance being known, we find according to Ohm's law:—

$$\text{Current} = \frac{\text{Electromotive Force}}{\text{Resistance}}\,;\ C = \frac{E}{R}$$

The unit of current is called the *Ampère*, a current of one ampère will deposit—electrolytically—19·7 milligrams of copper per minute.

From the above equation we get:—

$$\text{Current} \times \text{Resistance} = \text{Electromotive Force}$$

and the unit of electromotive force, the *volt*, may be defined as that electromotive force which in a circuit of the total resistance of one ohm produces a current of one ampère. Referring to the above remark that a Daniell's cell has an electromotive force of nearly one volt, it follows that when we close an element of that kind with a wire in such a way that the resistance of the element + that of the wire is = 1 ohm, we obtain a current of nearly one ampère.

Relation of Electrical Units and Units of Work.

We have already in the preceding paragraph shown the connection between the heat generated in a conductor, or, in other words, between the work done by the current, and its electromotive force, on the one hand, and the resistance of the conductor on the other. This work is, according to Joule's law:—

$$W = C^2 R = CE$$

By dividing these expressions by the velocity of a body falling through a vacuum (9·81 metres in one second), we find the work of the electric current in kilogrammetres:—

$$W = \frac{C^2R}{9\cdot 81} = \frac{CE}{9\cdot 81}$$

A further division by 75 (1 horse-power is equal to 75 kilogrammetres, in other words, can raise 75 kilogrammes through 1 metre, or 1 kilogramme through 75 metres) will give us the current work in horse-power* :—

$$W = \frac{C^2R}{9\cdot 81 \times 75} = \frac{CE}{9\cdot 81 \times 75}$$

To show the practical application of these equations let us assume that an installation of 100 20-candle Swan lamps is to be made. A 20-candle Swan lamp of the latest type requires a current 100 Volts × ·7 ampères; we then get $E\ C = 100 \times 100 \times \cdot 7$, and the number of horse-power (H.P.):—

$$H.\ P. = \frac{100 \times 100 \times \cdot 7}{9\cdot 81 \times 75} = 9\cdot 5$$

---

* In English measure, 1 horse-power is equal to 550 foot-pounds per second, and 1 horse-power can maintain a current of 1 ampère through 746 ohms; we therefore have: $W = \frac{C^2R}{746} = \frac{CE}{746}$.

For such an installation 9·5 electrical horse-power would be required.

§ 4. Distribution of Heat in an Electric Circuit.[*]

It is clear that, in order to obtain a certain heat effect, the form, material, dimensions, etc., of the conductor and its immediate neighbourhood, must be of such kind as to insure the required difference between those parts of the conductor where heat has to be developed for practical purposes, and those parts which merely serve for the conduction of the electric current.

On using galvanic batteries[†] the circuit consists not only of solid but also of liquid conductors (the battery charge), which generally oppose a much greater resistance to the passage of the current than even the worst metallic conductors;[‡] even the larger cross section of the liquid layers in the usual battery elements does not materially affect this property. A large amount of heat will therefore necessarily be developed within the battery (internal resistance of the circuit), and yet the liquid is but slightly heated, because on account of its larger cross-

---

[*] From Merling, 'Die Electrische Beleuchtung,' Braunschweig, Vieweg, 1884.

[†] Although the use of galvanic batteries for electric lighting has become almost obsolete since the invention of the dynamo, yet in certain cases galvanic currents must be used even now. This is the reason why their use is treated of in this place, and also because it will enable us the more easily to understand the principles of the light machine, as well as the behaviour of a moderate conductor (platinum, carbon, &c.) interpolated in the circuit in place of the voltaic arc.

[‡] If we assume the relative resistance of copper wire to be 1, we get for—

Concentrated nitric acid	=	1100000
„ sulphuric acid	=	500000
Dilute sulphuric acid (1 to 10)	=	750000
Concentrated zinc sulphate solution	=	1570000
„ copper sulphate	=	7500000
Distilled water	=	3000000000

section, consequently its larger mass, it absorbs more heat. The heating of the liquid in any case would diminish, not increase, the resistance, as it does in the case of solid conductors, and would thus have a favourable effect on the current.

The internal resistance (battery resistance) requires special attention, because on its relation to the resistance of the solid conductor depends the efficiency of the battery; we have therefore, on considering the total resistance R of the circuit, to distinguish: the internal resistance r from the resistance R_1 of the conducting wire (external resistance of the circuit). Ohm's law $C = \frac{E}{R}$ now is expressed as follows:—

$$C = \frac{E}{R_1 + r}$$

and on joining several (n) elements to form a battery—

$$C = \frac{n\,E}{R_1 + nr}$$

This will show that with the number of elements, the internal resistance r increases proportionately ($n\ r$). If the external resistance R_1 become an infinitesimal quantity compared with the internal resistance r, or, in our case, $n\ r$, we get $C = \frac{n\,E}{n\,r} = \frac{E}{r}$ from which follows that in such a case the electromotive force E cannot be increased by an increase of elements, because their number n appears both in the numerator and in the denominator of the fraction.

In a circuit of this description, that is to say, on the *short circuiting* of the electric source, an increase can only be obtained through an enlargement of the elements, that is to say, by enlarging the cross section of the liquid, or the immersed electrodes, by shortening their distance from one another, and thus diminishing the internal resistance r. Instead of altering the element itself, several elements* are generally joined into one by connecting them not *one after the other* (series) (Fig. 1), but one *along side of the other* (parallel) (Figs. 2, 2A, 2B).

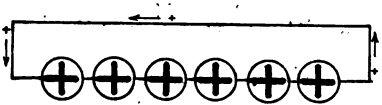

FIG. 1.

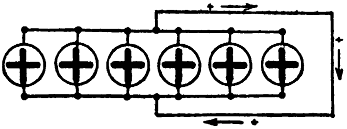

FIG. 2.

In the former case the internal resistance is nr, but in the case of Fig. 2 only $\frac{r}{n}$ and in the combinations Figs. 2A and 2B.

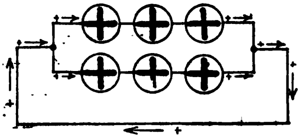

FIG. 2A.

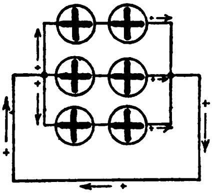

FIG. 2B.

$$\frac{\frac{n}{2}r}{2} = \frac{nr}{4}, \text{ and } \frac{\frac{n}{3}r}{3} = \frac{nr}{9}$$

Supposing the resistance r of one element to be 6 ohms, the internal resistance would be for

Fig. 1, $nr = 6 \times 6 = 36$ ohms (6 small elements).

---

* The circles in the figures signify the carbon or copper electrodes; the crosses, the zinc electrodes of the elements.

Fig. 2, $\frac{r}{n} = \frac{6}{6} = 1$ ohm (1 element of six times the size).

„ 2A, $\frac{n\,r}{4} = \frac{6 \times 6}{4} = 9$ ohms (3 elements of double size).

„ 2B, $\frac{n\,r}{9} = \frac{6 \times 6}{9} = 4$ ohms (2 elements of treble size).

By representing the internal resistance of each individual element in form of a solid conductor, we get, instead of Fig. 2, the combination expressed in Fig. 3.

Six metallic wires of 6 ohms resistance each are connected up in parallel, and joined into one single conductor of a cross section, six times as large. The resistance of this conductor is now six times smaller than that of each individual conductor.

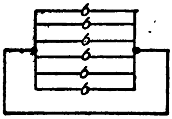

FIG. 3.

Instead of Figs. 2A and 2B, we now get the combinations, Figs. 3A and 3B.

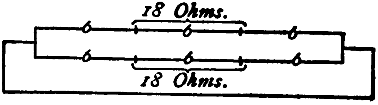

FIG. 3A.

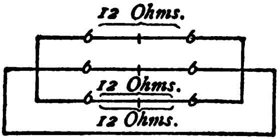

FIG. 3B.

In the former the resistance of one series is 18 ohms and the total resistance $\frac{18}{2}$, it is therefore the resistance of one series divided by the number of series; in the latter the resistance of one series is 12 ohms, and therefore the total resistance $= \frac{12}{3} = 4$ ohms.

These arrangements claim our attention even in cases where the external resistance cannot be neglected; for, with a given number of elements of definite form and size, and a given external resistance, *the maximum current is obtained by arranging the battery in such a way that its internal resistance is equal to the external resistance of the circuit.*

The necessary arrangement for connecting up a battery to satisfy this condition can easily be found by calculation. Let 4 ohms be the resistance R_1 of the external circuit, and 6 elements of 6 ohms internal resistance r be available, let x be the number of elements to be connected up in series, and their resistance $x\,r$, let y be the number of parallel series, then the total internal resistance of the combination is $\frac{xr}{y}$. We know that $xy = n$, therefore $y = \frac{n}{x}$, and therefore total internal resistance $= \frac{x^2r}{n}$. To obtain the highest efficiency we must have $R_1 = \frac{x^2r}{n}$, and from this we get $x = \sqrt{\frac{R_1 n}{r}}$, and by substituting the figures of our example we find $x = \sqrt{\frac{4 \times 6}{6}} = 2$, that is to say, the arrangement shown in Fig. 2b, 6 elements in 3 series of 2, gives the maximum effect. It follows from this that it is in certain cases possible to modify the internal resistance of a battery of a given number of elements in such a way as to obtain the highest efficiency. On considering the equations $C = \frac{E}{R_1 + r}$ and $C = \frac{nE}{R_1 + nr}$, C becomes maximum when by a suitable connection of the elements r, or, in our case, $nr = R$. Now, as the generation of heat in the circuit depends on the current C, we find, with regard to the distribution of heat in the circuit, that, whenever the resistance of the external circuit is excessively small in comparison to the internal resistance, the generation of heat can only be increased by enlarging the elements, in one word, all the conditions which influence the strength of the electric current have an analogous effect upon the generation of heat.

In the foregoing observations we have only considered one form of element, viz., the Daniell cell. Elements of different construction possess different electromotive forces, that of the Daniell cell having been adopted as unit.

The following figures express the relative electromotive forces of different battery materials:—

(+)	Zinc.	Iron.	Copper.	Silver.	Platinum.	Carbon.	Pyrolusite.	(−)
	0	75	100	109	123	200	220	

According to this

The zinc-pyrolusite element has the highest electromotive force	220–0 * =220
The copper-silver element—the smallest electromotive force	109–100= 9
The zinc-copper element—nearly the means between the two	100– 0=100

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* For the electrical condition at the pole-ends of a battery element, or any two points in the circuit, the scientific expression "potential" has been adopted.

Electromotive force, difference of potential, are strictly speaking not identical, but can mostly be used one for the other.

The above values for relative electromotive forces are given in reference to an arbitrary level (zinc = 0); in practice, however, electromotive force and potential are measured in a different way.

With the number of elements this difference of potential between the pole-ends of a battery increases. Fig. 4 gives a graphic representation of

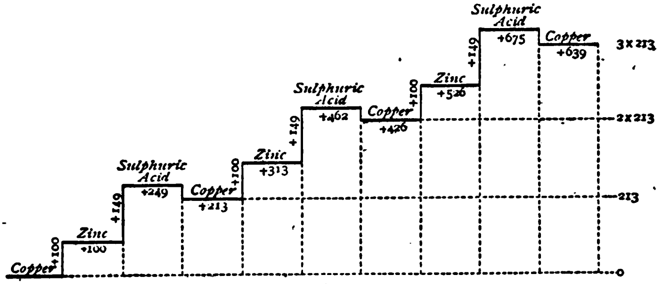

FIG. 4.

always provided the influence of the liquid charge and of disturbing internal actions is left out of consideration.

If, for the purposes of generation of heat, elements of higher electromotive force are available, the desired effect may be obtained by a lesser expenditure of material. In such a contingency, the influence of the electromotive force E is easily seen from equation $W = \frac{E^2}{R}$, and according to whether the external resistance R_1 or the internal resistance r of the circuit can be neglected, this equation would assume the following forms: $W = \frac{E^2}{R_1}$ or $W = \frac{E^2}{r}$. The same also holds good for the first equation of Joule's law: $W = C^2R$.

In considering Ohm's law we have only distinguished between the internal and external resistance of the circuit, but we must not lose sight of the fact that, as regards the utilization of heat, the external resistance consists of the resistance of the actual conductor (R_2) and the resistance of the moderate conductor (R_3) in which the desired heat effect is to be obtained. Ohm's law now reads

$$C = \frac{E}{R_2 + R_3 + r} \text{ or } C = \frac{nE}{R_2 + R_3 + nr}$$

and after Joule's law, $W = C^2R$, the heat generated in the moderate conductor (R_3) $W = C^2R_3$, whose maximum will be reached when with a *given battery and given resistance*

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the height of potential at different points of a battery formed of three voltaic elements, the current being taken from the copper pole.

The differences of potential are represented by ordinates, the difference of potential between copper and liquid and between zinc and liquid being taken as −36 and +149 respectively. In a similar way the electromotive force of the circuit falls to zero in the conductor (639–0) in proportion to the resistance of the latter; and the difference of potential of two points of the circuit is the smaller, the less the resistance between them.

of conductor, the resistance of the moderate conductor R_3 is equal to the remaining resistance of the circuit, that is equal to $R_2 + r$ and $R_2 + nr$. For simplicity's sake we may call this resistance R_4 and then get

$$C = \frac{E}{R_2 + R_3 + r} \text{ or } C = \frac{E}{R_3 + R_4}$$

By expressing R_3 of the moderate conductor as a ratio of resistance R_4, by xR_4 we have

$C = \dfrac{E}{xR_4 + R_4}$, and the heat generated in the moderate conductor xR_4 equal to C^2xR_4. By substituting in this equation the last value of C, the quantity of heat in the moderate conductor

$$= \frac{E^2 x\, R_4}{x^2 R_4^2 + 2\, x\, R_4^2 + R_4^2} = \frac{E^2 x}{x^2 R_4 + 2\, x\, R_4 + R_4} = \frac{E^2}{R_4} \times \frac{x}{(1 + x)^2}.$$

The factor $\dfrac{x}{(1 + x)^2}$ is maximum of the value $\frac{1}{4}$, when $x = 1$.

If therefore the conditions of resistance in the circuit are regulated in such a manner that the resistance of the moderate conductor is equal to the remaining resistance of the circuit, there will be, in the moderate conductor, *a maximum generation of heat amounting to one fourth of the heat which would be generated in the circuit without the interpolation of a moderate conductor.*

These considerations are most important for the arrangement of an electric light circuit; because in such a circuit electric light constitutes what we have called the moderate conductor, and we proceed therefore to explain these conditions by practical examples. For this purpose we choose the galvanic battery; or, in order to come nearer to the conditions of resistance in a practical light circuit worked by a dynamo, and for the sake of simplicity, the galvanic element with an internal resistance corresponding to that of the windings of a dynamo.

If electric lighting is to be carried out with a battery, the most powerful elements, as has been stated, must be employed. The Bunsen element is of such description. The external cylinder of gas carbon is immersed in nitric acid, whilst the zinc rod is placed in dilute sulphuric acid; the two liquids are separated by a cylinder of porous clay closed at the bottom, whose internal diameter is large enough to acccommodate the zinc electrode. If the two poles of the element are joined by a short wire of high conductivity, the element is, as we call it, *short-circuited*. In this case the heat generated by the current is almost exclusively developed in the interior of the element. In a short-circuited element we have only to take into account the internal resistance which in an ordinary sized Bunsen cell amounts to about 4 ohms. The heat generated in unit of time, or the work W done by the electric current, is $= C^2r$; $C = \frac{E}{r}$, therefore $W = \frac{E^2}{r}$.

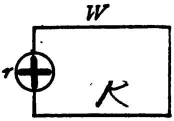

Fig. 5.

If instead of the short conductor of high conductivity, a longer wire is used (Fig. 5), whose resistance R cannot be neglected, we get $C = \frac{E}{r + R}$ and then $W = \frac{E^2}{r + R}$. The heat generated in the element is in the latter case distributed over the whole circuit; but in as far as we require a heat effect for the formation of light, we desire the greatest possible concentration of the heat given oft at one special point, or, in case of divided light, at some particular points of the external circuit, i.e. at such points where we require an electric light. This is effected by the interpolation at those points of moderate conductors (platinum wire, etc.), by whose incandescence the electric light is formed.

Fig. 6 shows a combination of this kind, where R_1 is the resistance of the moderate conductor. Here we have

$$C = \frac{E}{r + R + R_1} \text{ and } W = \frac{E^2}{r + R + R_1}.$$

In this combination we obtain, as will be remembered, the maximum current, by arranging the electrical source so that $r = R + R_1$ and the maximum heat effect in the moderate conductor when $R_1 = r + R$. In the same way as the total heat W in the circuit we calculate the heat W_1 expended in some special part of it. In the moderate conductor R_1 it is $C^2 R_1$; in our case therefore by substituting the value of C

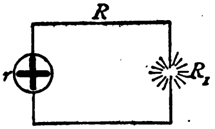

FIG. 6.

$$W_1 = \frac{E^2}{(\underset{r}{\cancel{R}} + R + R_1)^2} R_1.$$

Now if the circuit is arranged for generation of maximum heat ($R_1 = r + R$) then the heat expended in R_1 is one-fourth of the heat generated in combination shown in Fig. 5, that is to say, in a circuit without R_1. In no case can we obtain more heat for R_1.

If we want to obtain both maximum current and maximum heat we have to exclude resistance R from combination (Fig. 6); but as this is not feasible, R must, by the employment of a highly conducting wire of large cross section, be diminished to such an extent that it may be neglected as against r and R_1. If Fig. 7 represents a combination of this kind, we get, if $r = R$, both current and available heat maxima, and in R_1, an expenditure of one fourth of the heat generated in the short-circuited element.

On increasing the resistance R_1 of the moderate conductor, the current is weakened, the total generation of heat decreases, but the efficiency rises in proportion to the relative resistances of the individual parts of the circuit. Supposing the resistance of the desired combination to be 1 ohm*, then we have $C = \frac{E}{r} = \frac{1}{1} = 1$ and the heat generated within the short-circuited element $W = \frac{E_2}{r} = \frac{1^2}{1} = 1$, taking, for the sake of convenience, the electromotive force of the element also as 1. If, however, in combination (Fig. 7) there is a moderate conductor whose resistance is likewise $= 1$ ohm, then the total resistance of the circuit is $1 + 1 = 2$ and $C = \frac{1}{2}$ and the *total heat* generated in the circuit $W = \frac{1^2}{2} = \frac{1}{2}$, whilst the heat generated in the moderate conductor

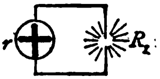

FIG. 7.

$$W_1 = \frac{1^2}{2^2} 1 = \frac{1}{4},$$

or half the total heat of the circuit, the second fourth belonging to the other half of the circuit. By doubling the resistance the current as well as the heat are reduced by one half, and equal parts of this half belong to the two equal resistances forming the circuit. This is *the maximum heat given off in the moderate conductor.*

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* The Bunsen element having an internal resistance of 4 ohms, 4 such elements would have to be coupled up in parallel, in order to form *one* large element of 1 ohm resistance.

On raising the resistance of the latter to 4 ohms, the total resistance of the circuit is 5 ohms, then $C = \frac{1}{5} = \cdot 2$ and *total heat* $W = \frac{1^2}{5} = \cdot 2$, whilst the heat W_1 generated in the moderate conductor

$$W_1 = \frac{E^2}{(r + R_1)^2} R_1 = \frac{1^2}{5^2} \times 4 = \cdot 16,$$

and in the other part of the circuit $\frac{1^2}{5^2} \times 1 = \cdot 04$. Although in the latter case the total heat (.2) amounts to less than half the total heat (.5) obtained by a combined maximum effect of current and heat, yet we find but a proportionately slight decrease of heat in the moderate conductor, from .25 to .16. This will show that it is possible, by an increase of resistance in the moderate conductor, to concentrate, for the purpose of utilization, the heat of the circuit at one particular spot; in other words, to withdraw heat from the remaining part of the circuit and to do so with a *lesser expenditure of current and consequently also of heat.* Such an arrangement is most desirable under certain circumstances, especially when it is a question of preventing the heating of the windings of a dynamo.* It is of course self evident that in order to obtain equal effects a relatively larger expenditure of heat in the moderate conductor requires a stronger electrical source.

By reducing to the lowest possible point the resistance in the generator, as well as in its connections with the light centre, the wasteful generation of heat will be effectually prevented. For the simplest practical purposes, where a light is supplied by a galvanic battery, the figures given above, i.e. 1 ohm resistance in the electrical source, nearly the same in the conductors, and up to 4 ohms in the light itself, are as a rule not exceeded. If the light is to be produced by means of Bunsen elements of 4 ohms internal resistance, it stands to reason that one element is not sufficient. Supposing there are 64 elements available we get according to the formula of p. 19—

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* All that has been said here of the battery is equally applicable to light circuits supplied by dynamos.

$$x = \sqrt{\frac{R\,n}{r}} = \sqrt{\frac{1 \times 64}{4}} = 4.$$

A battery of 64 elements would have to be arranged in 16 series of 4 elements, and this would give the desired battery resistance of 1 ohm; we should then in reality have a battery of only 4 elements of 16 times as large a size and of ·25 ohms resistance each. In this case we get the number of large elements, i.e. 4,* as the value of the electromotive force, and this would allow us to determine the current C as well as the heat W generated in the circuit, or in any part of the circuit.

We once more wish to point out that Ohm's law gives us the current only as a function of the total resistance of the circuit; while, with the help of Joule's law, we are enabled to find the heat generated in the whole circuit as well as in any particular part of it.

The employment of powerful elements for the production of electric light is justified by the fact of their higher electromotive force, their lower internal resistance, and also on account of the stronger current obtained, which, according to Joule's law, naturally generates more heat *in unit of time* than a weaker current. The total heat generated by a Bunsen element, or a Bunsen battery, has been found to be 1400 calories* for each kilogramme of zinc used up in the battery. The consumption of other materials in the battery corresponds to that of zinc, and we can therefore easily calculate the cost of a Bunsen battery for the maintenance of electric light. The cost of the zinc alone, if half the available heat $(\frac{1400}{2} = 700 \text{ calories})$ is rendered effective by combination (Fig. 7), is 7*d.*, or 3½*d.* for 1000 calories provided the zinc be protected from direct solution,† and the by-products, formed by chemical action within the elements, considered as valueless.

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* We have on p. 20 defined the electromotive force of the Daniell cell as unit. The electromotive force of the Bunsen element is equal to 1·65 Daniell, so that our value 4 would be 4 × 1·65 = 6·6, the electromotive force of the above combination.

The costs of the remaining materials, nitric acid, sulphuric acid, mercury, etc., come to five times as much as the expense of zinc, so that the total expense of the Bunsen battery is 3*s.* 7*d.* or 1*s.* 9*d.* for 1000 calories.

The remark made in foot-note, p. 26, must be repeated here, namely, that all the statements made with regard to the heat generated in an electric circuit are equally valid whatever be the source of electricity.

§ 5. EFFICIENCY OF DYNAMOS AND THEIR APPLICATION TO ELECTRIC LIGHTING.

It is only since the invention of the dynamo that electric lighting has come within the range of practical questions. The electric currents obtained from any battery we know at present, are on the one hand not powerful enough, and on the other hand too expensive to find practical application on a large scale. The principle on which dynamos are constructed and the details of their construction are treated in numerous text-books on this subject, and we are here merely concerned with their efficiency and application to electric lamps. As regards the choice of dynamos for a distinct, definite purpose, no general rules can be laid down. Each individual application presents distinct conditions of working, and consequently necessitates a distinct choice as regards the resistance of wires, size and number of revolutions of the machine, while on the other hand the electromotive force and the current of the machine are dependent upon this choice. As a general guiding rule we can only repeat the proposition at which we arrived in the case of batteries: the maximum effect is obtained by making the internal resistance of the dynamo equal to the resistance of the external circuit. At the same time we have to take into consideration the electromotive force required of the dynamo, which differs considerably according to the work the machine is destined for; for instance, whether it has to supply current for arc or glow lamps.

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* One calory is the quantity of heat required to raise one kilogramme of water through 1° centigrade.

† The direct solution of zinc is counteracted by amalgamating it; this latter process of course constitutes part of the expense. The heat generated by the solution is lost for the working, because the secondary action is deleterious as far as the formation of current is concerned, and the heat can *only be distributed by the current over the whole circuit.*

Supposing now our choice had been made, and a dynamo of sufficiently high electromotive force and of definite internal resistance selected, it will altogether depend upon these two quantities how the lamps have to be arranged in the circuit in order to obtain the most advantageous working conditions. Two entirely different arrangements are possible for lamps placed in one circuit; they can either be

1, *Connected in series*, or
2, *Arranged in parallel.*

Fig. 8 represents the former, Fig. 9 the latter case.

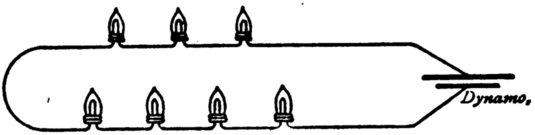

FIG. 8.

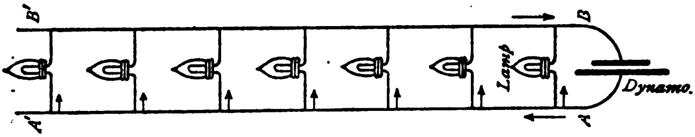

FIG. 9.

In Fig. 8 the whole current traversing the external circuit passes in its turn through every individual lamp; the current of each lamp is therefore equal to that of every other lamp in the same circuit, and also equal to the current supplied by the dynamo; while in Fig. 9, two stout wires *AA'*, and *BB'*, start from the dynamo, and connection is made between these wires by a number of lamps all mounted in exactly the same way. Each of these lamps now receives only a certain fraction of the whole current supplied by the dynamo.

By replacing the lamps of Figs. 8 and 9 by galvanic elements, dynamos or any other source of electricity, all of the same kind and connected up in the same way, and replacing the dynamos by the conductors traversed by the current, we get a graphic representation of a number of dynamos arranged in series or in parallel. In the former case we get an electromotive force increased in proportion to the number of dynamos, but at the same time a proportionately higher internal resistance; in the latter case the electromotive force is the same as that of one dynamo, but the internal resistance is lessened in proportion to their number. Circumstances must decide which of the two arrangements is desirable.

All electric lamps, whether arc or glow, require in order to produce a certain light effect, a definite current, which differs according to the type of the respective lamp; the ordinary glow lamp (16-candle Swan) for instance, takes a current of ·7 ampère, an arc lamp one of 10 to 40 ampères. The electromotive force and the internal resistance of the generator, which naturally depend on the resistance of the lamp, must be such as to exactly produce the requisite current. An arc lamp of average illuminating power requires an electromotive force of 50 volts and 10 ampères current. A 20-candle Swan lamp of 133 ohms resistance takes 100 volts and ·75 ampère. Provided now the conducting wires are sufficiently strong for the required current, it is clear from the above figures that we can substitute two arc lamps in series for each glow lamp, and that it is possible to run arc and glow lamps in the same circuit from the same dynamo, on condition however that through some arrangement in the dynamo the difference of potential in the conductors is kept constant.

The large illuminating power of the arc lamps, which naturally limits the number of lamps to be employed, even for a comparatively large area, and further the fact of their taking a relatively small electromotive force (50 volts), make it possible to run a considerable number of them in series in the same circuit.

The electromotive force in this case must be in proportion to the number of lamps; so, for instance, if 10 lamps of 50 volts each are connected in series, the E. M. F. of the dynamo must be $10 \times 50 = 500$ volts; 50 lamps (as is sometimes the case in America) connected in series would require 2500 volts, a tension which is positively dangerous, and ought on that score to be forbidden by law. In order to obtain these high tensions several dynamos connected in series are used instead of one machine; by this means the difference of potential in the wire coils of each individual machine is considerably lessened, and the wires protected from combustion. The great advantage of series connection for arc lamps is that the conductors need not be very stout, having to convey but a small current, whilst the drawback of the system lies in the fact that the individual lamps are not independent of one another.

The glow lamps on the other hand, on account of their comparatively small illuminating power—and this is exactly what makes them fitted for domestic lighting—will always be used in large numbers for a comparatively small area; and thus series connection, even with a small number of lamps, will be "a priori" excluded, as it would necessitate a potential which is practicably impossible. Of course there is the possibility of connecting a number of glow lamps in series, and arrange these series in parallel (compound parallel), but by doing this we lose the advantage of independence of each individual lamp, which the absolute parallel arrangement insures; if one lamp of any particular series is extinguished, all the lamps belonging to the series will share the same fate; while in the case of parallel connection (Fig. 9) the extinction of one lamp in no way affects the others. Nor need in this latter case the E. M. F. of the dynamo be proportional to the number of lamps used; it need only be kept constant, so as to correspond to the E. M. F. of each lamp.

Whilst the parallel arrangement implies a constant E. M. F. and a varying current, the series connection necessitates a constant current and varying E. M. F. In the former case the E M. F. of the dynamo need not exceed

110 volts, always provided that Swan lamps of 100 volts and ·7 ampère are used. The current would have to be proportional to the number of lamps, so that an installation of 100 lamps, for instance, would require a current of 70 ampères. For this purpose the conductors as well as the dynamo must be of a special kind; the conductor must be stout enough to convey the current without overheating; and the armature coils of the dynamo must be wound with the stoutest possible wire, in order to decrease as much as possible the internal resistance of the machine. The necessity of very stout and therefore expensive conductors is the only serious drawback to the parallel arrangement.

After this necessary digression we return to the subject of efficiency of dynamos. The current generated in a dynamo is the result of the transmutation of mechanical energy, supplied by a motor, into electrical energy; and the efficiency of a dynamo may be measured by the ratio of the mechanical energy thus converted to the whole amount of mechanical energy expended. That such a transmutation cannot be effected without a certain loss stands to reason. All machines, of whatever kind they may be, are subject to certain conditions and influences, such as friction against the surrounding atmosphere, friction in the bearings, sliding of the driving belt, etc., all involving a loss of efficiency; so that the statement of certain manufacturers of dynamos, that their machines convert 90% (Weston even goes as far as 98%) of the motive power into available current, must be received with considerable doubt. Only where the dynamo is driven directly by the motor it may be possible to convert 90% of the energy supplied by the motor into electricity, whilst in all cases, where the motor has to drive other machines as well, a loss of 20 to 25% will not be considered excessive

Experiments made by Marcel Deprez give 85% as the mean efficiency of dynamos. All these figures however represent the *total* electrical energy obtained by transmutation of mechanical energy and of this total electrical energy only part appears in the form of light in the voltaic arc. The reason for this is that the total amount of electrical energy generated does not reach the arc, or the carbon filament, but is partly expended in heating the conductors and the wire coils of the dynamo, partly in creating deleterious so-called Foucault's currents. The jury of the late Paris Exhibition has published some interesting details which are shortly summed up in the table given below. The expression "*total mechanical efficiency*" used in the table, means the ratio of the total electrical to the expended mechanical work; by "mechanical efficiency of the arc," is meant the ratio of the work actually measured in the arc to the expended mechanical work, and by "electrical efficiency of the arc," the ratio of the electrical work measured in the arc to the total electrical work. Thirteen different continuous current-machines were tested, and, according to the number of lamps driven simultaneously, divided into 3 groups.

	1 lamp.	2–5 lamps.	10–40 lamps.	Mean efficiency.
Total mechanical efficiency .	·89	·86	·84	·87
Mechanical efficiency of the arc	·47	·59	·71	·59
Electrical efficiency of the arc.	·53	·70	·84	·69
Candle-power per mechanical horse-power	880	960	800	864
Candle-power per ampère . .	129·6	105·6	60·8	96

The first line of the table shows that nearly 90 per cent. of the motive power is converted into electrical energy, and that the total mechanical efficiency is only dependent on certain local conditions, and has nothing to do with the details of the installation, which may be a single powerful light, or a number of lamps of comparatively small illuminating power.

The second line tells us what percentage of the expended mechanical work is available for illuminating purposes. This mechanical efficiency of the arc seems to be rather more favourable for machines of high resistance, that is, machines supplying a large number of lamps; the number of candles per ampère decreases in proportion to the number of lamps driven by a machine It also results from the above table that the illuminating power obtained with various machines and lamps is nearly constant, that by the expenditure of the same amount of mechanical work the same illuminating power is obtained independent of the degree of division of light.

It will be of interest to compare the efficiency of the dynamo with that of a galvanic battery. It has been shown on p. 28 that with a Bunsen battery the cost of 1000 calories is 1*s.* 9*d.*; to produce the same effect with a dynamo we have first of all to take into consideration the cost of producing the requisite motive power, by means of a steam or gas engine, and this cost is measured by the consumption of coal in the former, and of gas in the latter case.

Let us take the price of one kilogramme (about 2 lbs.) of coal at $\frac{1}{4}d.$; its heat of combustion is 7200 calories; a perfect steam-engine of large size will yield 1 horse power (75 kilogramme - metres) per hour with the said quantity of coal. This gives a total efficiency of $75 \times 60 \times 60 = 270{,}000$ kilogramme-metres per hour. The heat equivalent to work represented by 1 kilogramme-metre is $= \frac{1}{430}$ (in English measure the heat equivalent to 1 foot pound is $\frac{1}{772}$, that is to say that the work done in raising 1 lb. through 772 foot will raise 1 lb. of water 1° Fahrenheit), and the total work of 1 kilogramme of coal is therefore $\frac{27,000}{430} = 630$ calories, of which about 80–90 per cent. = 500 calories, are converted into electricity; so that 1000 calories cost $2 \times \frac{1}{4}d. = \frac{1}{2}d.$ as against 21*d.* on using a galvanic battery. With steam engines of medium size, which require 3 kilogrammes of coal per hour and horse-power, the cost naturally rises to $1\frac{1}{2}d.$ per 1000 calories.

An Otto gas motor consumes 6* kilogrammes of gas at a price of $\frac{9}{10}d.$ (heat of combustion 6120 calories), per hour and per horse-power, from which we get $2 \times \frac{9}{10}d. = 1\frac{4}{5}d.$ per 1000 calories.

So much as regards the cost of production; and now let us consider the relative conditions of the current produced. It is well known that currents for the production of an intense electric light must be several thousand times stronger than ordinary telegraphic currents. These latter generally have a current of ·014 ampère; so that if we assume an electric light current to be 5000 times stronger, we get 5000 × ·014 = 70 ampères. A less intense light, of course, requires less current.

A current of 12 ampères, flowing through a light-circuit of 6 ohms total resistance, has according to Ohm's law $(C = \frac{E}{R};\ E = CR)$ E.M.F. = 72 volts. This would correspond to about 72 Daniell elements. Batteries of an equal number of elements are frequently used in telegraphy, but are always of much higher total resistance. Such a battery of 72 elements would have a resistance of 5000 ohms, and this would give a current of $\frac{72}{5000} = \cdot 014$ ampères.

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* 1 kilogramme of gas = 1·61 cubic metres = 10,200 calories = $1\frac{1}{2}d.$ The figures above are based on the price of 3*s.* 4*d.* per 1000 cubic feet of gas.

If we increase the speed of a small short-circuited dynamo of 1·80 internal resistance from 200 to 1080 revolutions per minute, the electromotive force expressed in Bunsen elements steadily rises from 5 to 20.

This gives us $C = \frac{5}{1 \cdot 80} = 2 \cdot 8$† and $C = \frac{20}{1 \cdot 80} = 11$*, or increase of current from 2·8 to 11. To obtain this effect with a Bunsen battery we should require for the lower value 55 Bunsen elements of 4 ohms internal resistance, grouped in 11 parallel series of 5 elements each, and for the higher value 880 elements arranged in 44 parallel series of 20 elements each (v. p. 17). In such a combination the resistance of a larger element formed of 11 to 44 elements respectively, would be ·364 and ·09 ohms respectively, and this would give a total resistance for 5 large elements = $\cdot 364 \times 5 = 1 \cdot 82$, and for 20 large elements $\cdot 09 \times 20 = 1 \cdot 80$, corresponding to the internal resistance (1·80) of the dynamo employed.

These considerations clearly show the high efficiency of the dynamo. We see how many Bunsen elements would be required to produce an effect equivalent to that of a dynamo, not forgetting, however, that the current of a galvanic battery could not be kept even approximately constant. A short-circuited dynamo of course would no more be used in practice than a short-circuited battery; but we know already that, in order to obtain favourable results in electric lighting, the external resistance of the circuit must not to any considerable extent exceed the internal resistance of the machine. Given an external resistance of 2 ohms and a total resistance of 3·80 ohms, an increase of from 540 to 1080 revolutions per minute, will raise the electromotive force from 8 to 23 Bunsen elements, the current consequently from nearly 2 to 6; and this corresponds to a Bunsen battery of 8 elements in series of 8 (64 elements) and 23 elements in series of 23 (529 elements) respectively, at the same time bringing us nearer to the actual conditions of resistance in an electric light circuit.

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* 4·6 and 18·3 ampères.

In order to express these figures in the usual ampère units we must reduce the electromotive force to volts. The electromotive of the Bunsen element is 1·65 volts, 8 Bunsens $= 8 \times 1{\cdot}65 = 13{\cdot}20$ & 23 Bunsens $= 23 \times 1{\cdot}65 = 37{\cdot}95$ volts, and therefore $C = \frac{13{\cdot}26}{3{\cdot}80} = 3{\cdot}47$ and $\frac{37{\cdot}95}{3{\cdot}80} = 10$ ampères. The maximum current obtained with the dynamo employed in this experiment of 3·80 ohms total resistance was about 12 ampères.

A smaller Siemens' dynamo of ·75 ohms internal resistance (half of which belonged to the windings of the armature), and 1·6 ohms total resistance of the circuit, gave with the expenditure of one horse-power, an electromotive force of 37 volts and a current of 20 ampères.

The larger the machine the higher the efficiency; and if during the time of working the external resistance increases, the revolutions of the armature must increase likewise in order to maintain the efficiency. The work to be expended is, always supposed the current remain constant, theoretically proportionate to the resistance of the circuit. An increase of external resistance considerably modifies the ratio of the electromotive force to the number of revolutions; if high resistances are introduced in the circuit, the working becomes extremely sensitive to all influences, extraneous or any other kind. The least disturbance manifests itself by the unsteadiness of the light, and extinction frequently ensues. If the external resistance becomes too high, the machine stops altogether.*

The results given above were obtained with a circuit in which no light was burning, so that the influence of the arc was excluded.

Careful tests in a practical light circuit were made with four medium sized Siemens dynamos† and gave the following results:

Dynamo.	Ampères.	Volts.	Ohms resistance in the arc.
I.	50·36	79·98	·75
II.	57·30	86·50	·66
III.	43·29	75·26	·91
IV.	50·85	75·74	·66

The different resistances of these machines were:

Dynamo.	Resistance of Electromagnets.	Resistance of Armature.	Total Resistance.
I.	·295	·305	·600
II.	·300	·280	·580
III.	·290	·290	·580
IV.	·290	·305	·595

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* The limit at which machines wound with wire of low resistance no longer give any current is very low, and is already reached at 10 ohms, or less total resistance of the circuit. The limit varies with the resistance of the windings. An insufficient number of revolutions likewise affects the starting of the machine.

† *Electrotechnische Zeitschrift*, 1881, No. III. p. 108 and following.

The dynamos therefore differed very little from one another, and yet a considerable difference is to be noticed in their efficiency, even in the case of Nos. II. and III. which show the same resistance in the arc. Now, if such differences exist in machines of the same construction, we are bound to come to the conclusion that it is altogether impossible to construct dynamos of the same efficiency. We may also here call attention to the fact that the efficiency depends to a great extent on the number of working hours. The longer the hours the more the machine is heated, and this constitutes a limit for the available current. The currents obtained during short working hours therefore do not express the practical efficiency. So, for instance, in the case of the above machines the admissible maximum for continuous working amounted to but 36 ampères, while for six continuous working hours, with a current of 55 ampères, the temperature of the armature rose by 52° and that of the field magnets by 40°. A large Siemens' dynamo at 450 revolutions after two hours' work became so hot that the electro-magnets began to fire; the current at that time was 63·48 ampères, the electromotive force 76·2 volts, the resistance of the arc 640 ohms, and the increase of temperature of the field magnets about 72°C.

This shows that "caeteris paribus" the efficiency of the machine is the higher the better its ventilation, the more access the surrounding air has to the windings and other parts of the machine.

Extensive tests lately made with a large Siemens' dynamo of ·435 ohms* internal resistance, and with an armature of 288 windings, afford a thorough insight into variations of current (C) * and electromotive force (E) for varying external resistances and velocities of rotation.†

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* Of this resistance ·145 ohms belonged to the windings of the armature, and ·290 ohms to the windings of the field magnets, whose mean distance from the iron cores was 10·5 mm.

	I. For total resistance of 2·77 ohms.		II. For total resistance of 1·51 ohms.	
	C.	E.	C.	E.
100 revolutions per minute . .	·30	·83	·88	1·29
200 „ „ . .	·58	·161	14·70	23·08
300 „ „ . .	7·18	20·03	33·60	52·08
400 „ „ . .	19·90	55·92	45·90	72·06
500 „ „ . .	30·10	84·89	58·50	85·40
600 „ „ . .	40·20	108·14	65·60	103·80
700 „ „ . .	44·70	122·48		
800 „ „ . .	50·40	142·12		
900 „ „ . .	55·70	150·93		

	III. For total resistance of ·97 ohms.		IV. For total resistance of ·53 ohms.	
	C.	E.	C.	E.
100 revolutions per minute . .	6·90	6·35	38·80	18·62
200 „ „ . .	39·50	37·13	63·00	35·28
300 „ „ . .	58·40	56·65	88·20	49·40
400 „ „ . .	71·10	71·81		
500 „ „ . .	79·80	81·40		

The two columns with heading I. show an increase of current from ·30 to 55·7 ampères and of ·83 to 150·95 volts; columns II. show that through a lesser resistance, a considerable increase already takes place on raising the number of revolutions from 100 to 200; the same we remark in column III., while from column IV. the machine being nearly short-circuited, we find that the E. M. F. increases in proportion to the velocity of rotation. In column I. this proportionality only manifests itself at 500 revolutions; in columns II. at 300, and in columns III. already at 200

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* The current was ascertained by direct measurements.

† The figures express the number of revolutions with very slight variations.

revolutions. The irregularities in the value of E. M. F. increase with the increase of the external resistance.

At a uniform velocity of 100 revolutions per minute and a total resistance of

·48 ohms we find C 38·8 and E 18·62
·65 „ „ „ 27·50 „ 17·88
·92 „ „ „ 6·90 „ 6·35
1·25 „ „ „ 1·06 „ 1·33
1·47 „ „ „ ·88 „ 1·29
1·95 „ „ „ ·38 „ ·74
2·47 „ „ „ ·29 „ ·72
2·77 „ „ „ ·30 „ ·83

At 200 revolutions per minute and a total resistance of

·56 ohms we find C 63·00 and E 35·28
·72 „ „ „ 50·90 „ 36·65
·94 „ „ „ 39·50 „ 37·13
1·31 „ „ „ 27·50 „ 36·03
1·57 „ „ „ 14·70 „ 23·08
2·01 „ „ „ 1·88 „ 3·78
2·51 „ „ „ 1·20 „ 3·01
2·78 „ „ „ ·58 „ 1·61

At 300 revolutions per minute and a total resistance of

·56 ohms we find C 88·20 and E 49·39
·73 „ „ „ 71·30 „ 52·05
·97 „ „ „ 58·40 „ 56·65
1·33 „ „ „ 41·50 „ 55·20
1·55 „ „ „ 33·60 „ 52·08
2·02 „ „ „ 23·70 „ 47·07
2·52 „ „ „ 15·50 „ 39·06
2·79 „ „ „ 7·18 „ 20·03

At 400 revolutions per minute and a total resistance of

·73 ohms we find C 95·20 and E 69·50
1·01 „ „ „ 71·10 „ 71·81
1·37 „ „ „ 53·40 „ 73·16
1·57 „ „ „ 45·90 „ 72·06
2·04 „ „ „ 33·90 „ 69·16
2·54 „ „ „ 25·90 „ 65·79
2·83 „ „ „ 19·90 „ 56·32

Revolutions.	Total resistance.	Current.	Variations of E. M. F.
500	1·02 to 2·82	79·8 to 30·1	81·4 to 84·9
600	1·43 „ 2·91	65·6 „ 35·3	103·8 „ 102·7
700	1·74 „ 2·98	67·7 „ 41·5	117·6 „ 123·7
800	2·22 „ 3·03	59·9 „ 45·6	133.0 „ 138·2
900	2·71 „ 3·11	55·7 „ 49.2	151·0 „ 153·0

For practical purposes the number of revolutions lies between 400 and 500 with a current of from 20 to 50 ampères; this limit must not be exceeded for fear of overheating the machine. The total resistances at 400 revolutions are 2·83 to 1·57 ohms, and at 500 revolutions 2·82 to 1·75 ohms, and this gives external resistances of 2·395 to 1·35 at 400 revolutions and 2·385 to 1·315 at 500 revolutions per minute.

The smaller the machine the larger must be the number of revolutions for the purposes of efficiency; so, for instance, for the medium size and smaller type of the Siemens continuous current machine, 700, 900 and 1200 revolutions have to be adopted. The wear and tear, especially of the bearings, is consequently very great. In practice, therefore, irregularities both of current and E. M. F. are to be avoided; wherever we find the two values very small in the above tables we have almost invariably to look for the cause to the remanent magnetism of the iron cores (the real primitive force of dynamos), where no strengthening of magnetism has yet taken place from the action of the currents.*

To show the influence of the number of windings the same machine was tested with 856 windings of the field magnets; the resistance of the latter was ·580 ohms, and their iron cores had a mean distance of 21 mm. from the windings. (Total resistance of the machine ·580 + ·145 = ·725 ohms.) Through a total resistance of 2·09 *ohms*

at 200	revolutions	C	18·4	and E	39·01
„ 400	„	„	40·9	„	86·70
„ 600	„	„	62·9	„	130·83

through a total resistance of 1·31 *ohms*

at 200	revolutions	C	32·1	and E	40·77
„ 400	„	„	67·7	„	87·33

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* It is taken for granted that the magnetism is strengthened not only by current action, but also by the number of windings of the field magnets.

whilst the former winding of the field magnets (v. footnote, p. 40) and the same total resistance gave

at 200 revolutions C 1·88 and E 3·78
„ 400 „ „ 33·90 „ 69·16
„ 600 „ „ 48·60 „ 106·00

and

at 200 revolutions C 27·5 and E 36·53
„ 400 „ „ 53·4 „ 73·16

A third winding of the same machine, namely, 1960 windings in the field magnets, of 4·14 ohms resistance, and 14 mm. mean distance from the iron cores, and 1296 windings in the armature of 3 ohms resistance (total resistance of machine = 7·14 ohms), gave through a total resistance of 19·1 *ohms*

at 200 revolutions C 7·95 and E 151·05
„ 300 „ „ 12·60 „ 241·92

through a total resistance of 23 *ohms*

at 200 revolutions C 5·95 and E 135·07
„ 300 „ „ 10·20 „ 234·60
„ 400 „ „ 13·60 „ 316·88

We have now to proceed to the question of the amount of mechanical work expended in producing the current, and from tests also made with a large Siemens dynamo of ·44 ohms internal resistance, the total resistance being ·92 ohms, we find:

Horse power.	Ampères.	Revolutions.	Current per horse power.
3·57	46·4	250	13·00
4·74	53·7	300	11·33
6·09	59·9	350	9·83
7·65	66·8	400	8·73
9·26	72·8	450	7·86

total resistance being 1·38 ohms:

Horse power.	Ampères.	Revolutions.	Current per horse power.
1·89	27·8	250	14·70
3·21	36·5	300	11·37
4·37	42.8	350	9·80
5·53	48·0	400	8·70
6·82	52·2	450	7·65

Tests made at the Paris Exhibition gave the following results:

	Total Resistance.	Current.	Revolutions.	H.P.	Ampères per H.P.
Siemens .	2·28	35·0	737	4·44	7·90
	5·21	26·2	1330	5·31	4·93
	35·25	10·0	826	5·05	1·98
Gramme .	·92	109·2	475	16·13	6·77
	10·17	19·0	1695	8·11	2·34
	21·49	15·3	1496	8·00	1·91
Brush . .	211·38	9·5	700	29·96	·32

Applying Ohm's law $C = \frac{E}{R}$ we find the electromotive force, the product of current and resistance, total resistance being ·92 ohms:

Volts.	Volts per H.P.
H = ·92 × 46·4 = 42·69	12·00
·92 × 53·7 = 49·40	10·43
·92 × 59·9 = 55·11	9·05
·92 × 66·8 = 61·46	8·03
·92 × 72·8 = 66·98	7·53

total resistance being 1·38 ohms:

Volts.	Volts per H.P.
E = 1·38 × 27·8 = 38·36	20·30
1·38 × 36·5 = 50·37	15·70
1·38 × 42·8 = 59·06	13·51
1·38 × 48·0 = 66·24	11·98
1·38 × 52·2 = 72·04	10·56

The Paris tests gave:

	Volts.	Volts per H.P.	
E =	2·28 × 35 = 78·80	18·00	Siemens.
	5·21 × 26·2 = 136·50	25·70	
	35·25 × 10 = 352·50	69·90	
E =	·92 × 109·2 = 102·00	6·32	Gramme.
	10·17 × 19·0 = 193·00	23·80	
	21·49 × 15·3 = 328	41·00	
E =	211·38 × 9·5 = 20·09	67·05	Brush.

To express the efficiency of a machine for electric lighting, the obtainable candle-power is sometimes given instead of current and E. M. F.: for instance, Siemens machines of 700, 1200, 3000 and 12,000 candle-power, at 1200, 900, 700 and 450 revolutions per minute respectively. We must however not lose sight of the fact that dynamos may be enlarged in order to raise their efficiency, and that certain types have been constructed of such size as to yield up to 40,000 candles. When we express the efficiency of a machine in candles, we do not mean that the machine can only be used for an installation employing that definite number of lights. To obtain a certain candle power, certain conditions must be fulfilled; the fulfilment does not depend however on the machine alone, but also on the conductors and different other lighting arrangements. We have already shown in § 4. that different illuminating powers can be obtained from the same generator.

This simple fact will conclusively prove that the expression of efficiency in candle-power is thoroughly unreliable, and experience has shown over and over again how very little credence can be attached to similar statements. We confine ourselves here to the remark that a medium size dynamo of good construction, such as are in common use now, at a uniform speed of 780 revolutions per minute, and under otherwise favourable conditions, can, when feeding an arc lamp, give 1700 candles per horse-power; in a general way, however, we only count upon 1000 candles. Further tests with different medium sized and large Siemens dynamos gave the following results.

The variations were:

Current between 36 and 97 ampères.
Electromotive force between 66 and 86 volts.
Work in the whole circuit between 3·36 and 10·56 H.P. per second.
Work in the arc between 1·95 and 5·23 H.P. per second.
Resistance of the arc between ·38 and 1·11 ohms.

From Joule's law we get the work expended in horse-power per second = $C^2R \times \cdot00181 = CE \times \cdot00181$, and by taking the mean of the values given above

$$\left(\frac{36 + 97}{2} \text{ and } \frac{66 + 86}{2}\right),$$

i.e. 66·5 & 76, we find the work expended per second by the machine = $66\cdot5 \times 76 \times \cdot00181 = 9\cdot15$ horse-power, and consequently the mean total electric work in the whole circuit* . . . . . . 75 per cent., and the available work in an arc of ·745 ohms resistance . . . . . . 49 per cent. The table on the following page embodies the results of the Paris tests:

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* The work done by the electric current, according to Joule's law, is $C^2R = \frac{E^2}{R} = \frac{CE}{R}$. By dividing these expressions by the velocity of a body falling through a vacuum (9·81 m.) we get the work of the current in kilogramme metres, and by further dividing by 75 (mkg.) in horse-power. If therefore the current C, or the electromotive force E, and the resistance of the circuit are known, the work of the current can be calculated from $\frac{C^2R}{9\cdot81}$ or $\frac{E^2}{R \times 9\cdot81}$ respectively $\frac{CE}{9\cdot81}$. From our mean values for $E = 76$ and $C = 66\cdot5$, R is nearly $= \frac{76}{66\cdot5} = 1\cdot143$, and the work of the current $= \frac{66\cdot5^2 \times 1\cdot14}{9\cdot81} = \frac{76^2}{1\cdot143 \times 9\cdot81} = \frac{66\cdot5 \times 76}{9\cdot81} = 515$ mkg. = 75%. The work expended by the machine was = 9·15 H.P. = 686 mkg. In the same way we find the work done in the arc.

		Formulae.	Siemens Machine.			Gramme Machine.			Brush Machine.	Remarks.
			No. of lamps fed. 1	2	3	No. of lamps fed. 1	3*	5	No. of lamps fed. 40.	
Mechanical Measurements	Revolutions	per minute	737	1330	826	475	1695	1496	700	
	Effective work	Horse-power (H.P.	4·44	5·31	5·05	16·13	8·11	8·00	29·96	Work of the Motor.
Electrical Measurements	Resistance of Machine	Ohms.	·66	1·68	7·05	·33	·52	4·57	22·38	
	,, ,, circuit †	,,	·12	·13	4·50	·10	1·25	·62	2·60	
	Total resistance	,, (R)	·78	1·81	11·55	·43	1·77	5.19	24·98	
	Current ‡	Ampères (C.)	35·00	26·20	10·00	109·20	19·00	15·30	9·50	
	E. M. F. § between lamp terminals	Volts (E)	53·00	44·50	47·40	53·00	53.00	49·80	44·30	
Electrical Calculation	Work in whole circuit	$\frac{C^2R}{75\times 9\cdot 81}$	1·29	1·69	1·57	6·97	·87	1·65	3·07	
	Work in one lamp	$\frac{E\,C}{75\times 9\cdot 81}$	2·52	1·59	·64	7·87	1·37	1·04	·57	
	Work in all lamps	Horse-power (h.p.)	2·52	3·18	3·20	7·87	4·11	5·20	21·88	
	Total work	,, (W.)	3·81	4·87	4·77	14 84	4·98	6·85	24·95	
	Mean E. M. F. in circuit	$nE + C\,R$	80	136	353	102	193	328	2009	
Efficiency	Total mechanical	W : H.P.	86	·92	·94	·92	·62	·86	·83	
	Total in the arc	h.p. : H.P.	·57	·60	·63	·43	·51	·65	·73	
	Total electrical	h.p. : W.	·66	·65	·67	·53	·83	·76	·87	
	Resistance of the arc	E : C.	1·50	1·70	4·74	·49	2·80	3·26	4·66	Approximately.

* A shunt within the field-magnets interfered with the efficiency.

† Wire connection between machine and lamps.

‡ Equal in all parts of the circuit.

§ Different in different parts of the circuit.

Although this table does not afford an opportunity for an actual comparison between the different machines, the conditions under which the tests were made not being equal, it yet contains details which enable us to form an independent judgment.

The chief aim is to obtain in the arc the largest possible amount of the work expended. Whether the results obtained are to form the basis for practical working must be decided by experience, taking into consideration the heating of the machine.

An official summing up of comparative tests, published in the *Electrotechnische Zeitschrift*, 1881. No. 2, p. 67, would point to a superiority of the Gramme over the Siemens machine for the following reasons: it has a higher efficiency of the arc, it requires less personal attention, there is less sparking in the commutator, and consequently less waste of commututors and brushes, and finally the position of the brushes is more easily regulated. Of special interest is the observation that in a Gramme machine the field magnets are more strongly heated than the revolving armature, while in a Siemens machine the reverse is the case. This would prove of no inconsiderable practical value, for it enables the person in charge to control the heating of the machine without stopping its working. High electromotive force is especially desirable where it is a question of increasing the number of lights burning in a circuit. The number of revolutions however, one of the main factors of the E. M. F., soon reaches a limit which must not be exceeded; and in the same way the number of windings of the armature is limited by the space intervening between it and the poles of the field magnets, and finally magnetic saturation will put a limit to the strengthening of the magnetic field. The enlargement of the dynamo itself is another means of increasing the efficiency; but this expedient, too, brings with it certain drawbacks, and can only be resorted to where the mode of construction, as in the Brush machine, presents a certain greater elasticity.

Efficiency of Dynamos at the International Health Exhibition of 1884.

The largest electric light installations ever made in this country are those of the Health Exhibition in 1884, and of the Inventions Exhibition in 1885; and, as a practical illustration of the general remarks and observations on the efficiency of dynamos given in the preceding pages, it will be of interest here to give a table showing the performances of different machines used at the former Exhibition.

The figures given are the results of measurements taken on that occasion, and it is to be regretted that no tests of any kind were made at the recent Inventions Exhibition, either with dynamos or lamps, and that no official record exists of the extensive installations carried out inside the building.

It is with no intention of criticising the comparative merit of the various machines, but simply with the view of affording valuable practical information, that these results are incorporated in this book.

On referring to the table it will be found that the Siemens lamp No. 3 shows a rather low efficiency; this is explained by the fact that the lamps were arranged in parallel, and that there was consequently a waste of energy in the artificial resistances employed.

As regards No. 5, the small current of 6·7 ampères of the Ball Unipolar machine would naturally give a relatively low efficiency in the arc.

DYNAMOS AT THE INTERNATIONAL HEALTH EXHIBITION, 1884.

Name of Dynamo.	Alternating or Direct Current.	E. M. F. at terminals.	Ampères Current.	Area of Illumination in square feet.	Name of Lamp.	Number of Lamps.	Actual Candle power per Lamp.	Total Candle power.	Efficiency of Dynamo Candle power per H.P.	Number of Dynamos.	Remarks.
1. Brush.	Direct	1,100	9·2	13,800	Brush	22	800	17,600	1,300	1	Arc Lamps.
2. Brush.	„	2,000	8·17	45,000	Brush	40	800	32,000	1,500	1	
3. Siemens	„	77	168	27,500	Siemens	4	5,500	22,000	1,270	1	
4. Siemens	Alt. W_3	290	10·5	Outside	Siemens	12	500	6,000	1,460	1	
5. Ball's Unipolar . .	Direct	680	6·7	Outside	Ball's	11	750	8,250	1,370	1	
6. Gramme	„	250	20·1	Outside	Lea	5	2,500	12,050	1,870	1	
7. Gramme	„	352	17	16,800	Brockie	7	2,000	14,000	1,780	1	
8. Hochhausen . . .	„	1,300	9·2	63,100	Hochhausen	26	800	23,200	1,300	1	
9. Hochhausen . . .	„	310	21	Mast Lts. Outside	Hochhausen	6	2,000	12,000	1,420	1	
10. Phoenix	„	336	12·25	10,400	Clark & Bowman	7	900	6,300	1,145	1	
11. Gramme	Alt.	250	7	31,900	Jablochkoff	60	550	33,000	850	4	
12. Edison	Direct	110	679	..	Edison-Swan	970	16–20	15,520	155	7	Glow Lamps.
13. Siemens	Alt.	180	152	..	Swan	1,080	20	21,600	150	2	
14. Opperman	„	..	..	..	Woodhouse & Rawson	234	20	4,680	..	1	
15. Siemens	Alt. W_1	88	215	..	Swan	216 40	20 10	4,320 400	186	1	
16. Victoria	Direct	97	72	..	Victoria	100	20	2,000	212	1	
17. Victoria	„	95	70	..	Victoria	60	20	1,200	135	1	
18. Elphinstone & Vincent	„	96	204	..	Gatehouse	282	20	5,640	215	1	

The very high efficiency of No. 6 arises from the arrangement of carbons in the Lea lamp. The upper carbon is considerably thinner than the lower one, having a diameter of 12 mm., while the lower carbon has a diameter of 18 mm.

As regards No 14, no reliable measurements could be taken, as the Opperman machine was constantly breaking down, and the Woodhouse and Rawson lamps had to be fed from some other machine.

It is clear that No. 17 Victoria machine was not working up to its full capacity, and that a great part of the energy must have been wasted in artificial resistances; the lamps used were the same as in No. 16, and the machine was of nearly the same power; while in the latter case the efficiency is 212 candles per H.P., and in the former only 135.

Finally the mean efficiency of the arc light machines was 1440 candles per H.P., while the glow lamps only yielded 175 candles per H.P.

The mean life of the glow lamps was a little under 400 hours.

§ 6. ELECTRIC MEASUREMENTS.

The electric current passing through a circuit produces heat for the maintenance of electric light; the stronger the current the greater its effect. In order to determine at any time the current and its electromotive force appropriate instruments are used for direct measurements. We confine ourselves here to the description of those instruments which are in general use in this country.

These instruments may, according to the different effects of the current, be divided into 3 groups.

1. Galvanometers based on the mechanical action of

a conductor traversed by a current on one or several magnets.

2. Dynamometers based on the mechanical action of a conductor traversed by a current—upon a second conductor likewise traversed by the current.

3. Voltameters based on the chemical decomposition of a liquid traversed by the current.

As regards their practical application we draw the following distinctions:

Galvanometers may be used for the strongest as well as the feeblest continuous currents.

Dynamometers are applicable for alternating as well as for continuous currents, but not nearly as sensitive as the former for feeble currents.

Voltameters are mostly used in cases where the chemical action of the current has to be determined.

All galvanometers are constructed after the same principle; they consist of a number of fixed wire coils actuating a magnet movable over a graduated disc around a vertical axis. They are as a rule only used for feeble continuous currents, such as find practical application in telegraphy and telephony. If a simple galvanometer is to be used for measuring currents, such as are produced by a dynamo, the instrument must be placed in a shunt, that is, only a certain small portion of the current must be allowed to pass through it, and the total strength determined from the respective resistances of the shunt.

A direct measurement of a dynamo current however can be effected by means of

Siemens' Electro-dynamometer.

Fig. 10 shows the construction of this instrument. W is a fixed coil consisting of a number of windings of copper wire of 3 mm. diameter, W^1 a movable coil of one or more windings of stout wire suspended by a spiral spring *f* ending in a screw nut *s*. The plane of the movable coil when at rest is at right angles to that of the flat fixed coil. Screw nut *s* carries a pointer Z, movable over a graduated disc S. A thin metallic strip Z^1 is fastened to coil W^1 and reaches with its free end over the graduated disc; W^1 dips with both its ends into mercury. When the instrument is to be used, both Z and Z^1 are brought to zero, the current passing in the direction of the arrows through both coils, displaces coil W^1, and with it the point of Z^1 on the disc. By turning screw nut *s* the latter is brought back to zero, pointer Z describes an angle, which indicates the torsion of spiral spring *f*, and this angle is proportional to the square of the current which has displaced coil W^1. According to Joule's law ($W = C^2 R$) the work W (heat generated) is proportional to the square of the current, so that the instrument is especially convenient in those cases, where, as in electric

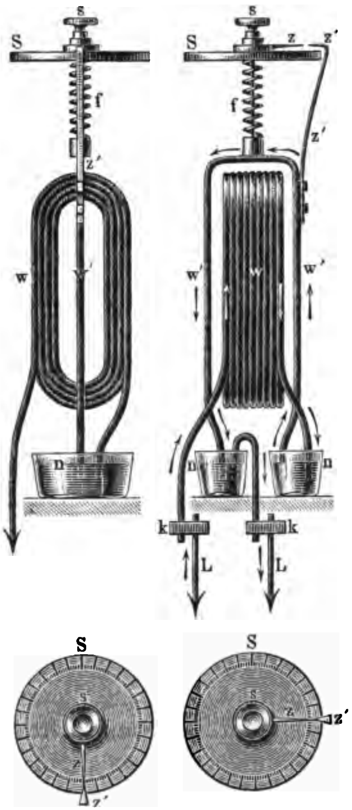

FIG. 10.—SIEMENS' ELECTRO-DYNAMOMETER.

lighting, it is a question of conversion of heat whose measure can be directly expressed by the angle of torsion. The expression of the current in ampères is easily effected by inscribing the respective current on the instrument. If the resistance R of the circuit is known, the E. M. F. is found from the equation E = C R.

A most convenient instrument for a direct measurement of currents from 45 to 90 ampères by simple deflection of the needle is

Ayrton and Perry's Ammeter.

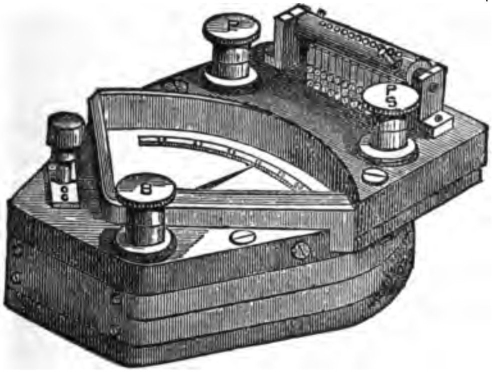

Fig. 11.—Ayrton and Perry's Ammeter.

The wire coils surrounding the needle are here so arranged that the deflection is proportional to the current. These coils consist of 10 insulated stout wires which, by means of a small commutator C, can be connected either in series or parallel. The wires have the same resistance, ·03 ohms generally, so that with the "quantity" arrangement, the current is uniformly divided. Besides its quick vibrations of short duration the magnetic needle which is placed between the poles of a powerful horseshoe-magnet, shows no troublesome oscillations.

The series connection lies between screw nuts PS and S, the parallel connection between PS and P, whilst, by means of a plug on the lower left of the figure, a special fine wire of 1 ohm resistance can be introduced in the series connections, and the accuracy of the instrument can thus be tested. For this purpose, or the calibration of the instrument respectively, we determine the deflection (a°) of the current of one galvanic element of known E. M. F. (E) by insertion of the plug 1 and deflection (β°) by its removal; we thereby find the resistance x of the circuit, i.e. the resistance of the element and its connection, inserting the plug, from

$$C : C_1 = x + 1 : x$$
$$La : L\beta = x + 1 : x$$
$$a - \beta : \beta = (x + 1) - x : x$$
$$x = \frac{\beta}{a - \beta} \text{ ohms,}$$

and the current in series connection $\dfrac{E}{\dfrac{\beta}{a-\beta}} = \dfrac{E\,(a-\beta)}{\beta}$ ampère

and in parallel arrangement $10\,\dfrac{E\,(a-\beta)}{\beta}$ ampère.

The latter is the usual working arrangement.

The current in series connection gives a deflection of a, therefore $\dfrac{E\,(a-\beta)}{a\beta} = 1$ degree, and the current $10\,\dfrac{E\,(a-\beta)}{a\beta}$ in parallel arrangement equally a deflection of 1 degree, according to which 1 degree of the parallel arrangement = 10 degrees of the series connection, so that with the latter lesser currents too, as they occur in incandescence lighting, can be measured. The wires of the dynamo being connected to the binding screws PS and P, the circuit can only be closed by placing the commutator in parallel, whilst by placing it in series the circuit is opened. In the same way the circuit which incloses S is opened by placing the commutator in parallel, so that in every case the instrument is guarded against damage arising from current action.

Another instrument largely used in practice is

Ayrton and Perry's Voltmeter.

The principle of construction is the same as that of the ammeter, which latter instrument it also resembles in form. The total resistance of the wires connected in series is 400 ohms, arranged for quantity 4 ohms; but it can also be constructed for higher values. The instrument is *calibrated* by arranging the commutator (Fig. 11) *for quantity*, and is used for high E. M. F. *in series connection;* with the former arrangement as low as 2 or 3 volts can be measured.

In series connection of the commutator a deflection of 1° corresponds to 1 volt or also to 5 volts, so that in the latter case by a deflection of 45°, 225 volts can be measured.

To calibrate the instrument the commutator is placed in a shunt, and one element of known electromotive force, E, is interpolated, and deflection α° observed; by withdrawal of the plug, a resistance of 4 ohms is added to the circuit, whereby the needle is deflected by β°. From this the electromotive force, or difference of potential between the respective terminals of the instrument is found $10 \; \dfrac{E\,(\alpha-\beta)}{\alpha\beta}$ Volt, and 10 degrees deflection in the "quantity" arrangement correspond to 1 degree of the series connection.

The Voltmeter is, in the same way as the Ammeter, guarded against damage arising from current action. In order to preserve the magnetic strength of the horseshoe magnets they are, when not in use, provided with an armature of soft iron.

In order to guard against errors arising from loss of directing force on part of the permanent magnet, Ayrton and Perry have regulated the action of the needle by means of a spiral spring, and the instruments thus modified are called *spring ammeter and spring voltmeter.* In these instruments zero is not in the centre of the scale, as in Fig. 13, but at one end, and the pointer can only oscillate in one direction as far as 45°. By altering the tension of the spiral spring, the sensitiveness or, in other words, the efficiency of the instrument can be raised in such a manner that the needle only begins to oscillate when a current of a certain greater strength acts on it. These spring instruments also permit the measuring of alternating currents.

More sensitive still are the *wheel and pinion ammeter and voltmeter*, by means of which up to 1200 ampères can be measured with security.

A most interesting measuring instrument has quite lately been submitted to the "Académie des Sciences," and which deserves mention on account of its extreme simplicity. It is

Lalande's Ampère Meter.

With the instruments mentioned above for direct determination of current and E. M. F. a frequent calibration is necessary, consequent upon the influence of terrestrial magnetism, and also variations of the magnetic condition of the magnets themselves.

Lalande's apparatus, for which he suggests the name of *Electric Areometer*, consists of a bundle of soft iron wire placed in the interior of a metallic areometer, which latter is inserted in a gauge full of water and surrounded by a coil, through which the current to be measured, passes. Under the action of the current, the bundle of wire is attracted, and the areometer is more or less displaced according to the strength of the current, and the amount of displacement is read off on a vertical scale fixed to the top of the instrument, which has been graduated by experiment. The guiding of the areometer rod is effected by a metallic needle-eye in the interior of the liquid, and this arrangement prevents any friction against the sides of the gauge, and does not affect the sensitiveness of the areometer. By varying the dimensions of the coil, and those of the bundle of wire, or of the areometer rod, the range of observation can be varied at will. In the instruments constructed at present a displacement of about 10 centimetres, corresponds to a current of from 10–25 ampères, or to a difference of potential of 100 volts.

The coils of the ampère meter are formed of one or two windings only of very stout wire of ·01 or ·02 ohm, and the apparatus can be introduced without any inconvenience in most electric circuits. The coil of the voltmeter is of fine wire, and represents a resistance of about 1700 ohms.

The apparatus is not sensibly affected by variations of temperature; its readings are not interfered with by the neighbourhood of metallic masses, or even by powerful magnets, and its sensitiveness is very great.

For measuring large resistances, so-called *Resistance Boxes* are used of the form shown in Fig. 12.

By means of metallic plugs different resistances, consisting of coils wound with German silver, can be introduced into the circuit, or withdrawn from it. If all the plugs are removed, the sum of all the resistances is introduced; if all the plugs are inserted, the box is short circuited.

For practical measurements of resistances the principles underlying these methods may briefly be given.

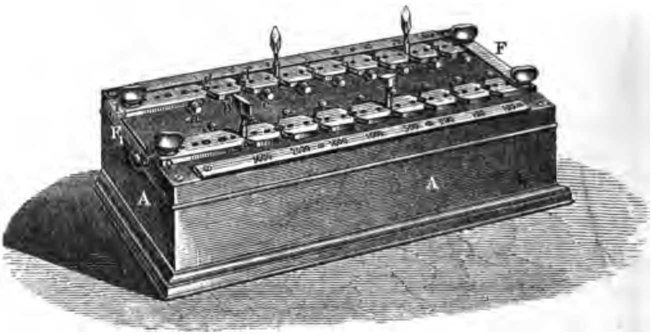

FIG. 12.

If we connect two equal galvanic elements in series (Fig. 13), and pass the current through the coils of an ordinary galvanometer, the needle of the galvanometer will be deflected. On connecting the elements for quantity (parallel arrangement, Fig. 14) in such manner that the positive current enters the galvanometer on both sides the needle remains at rest, the effect of the two equal currents being neutralized.

We now interpolate in the simple combination of wires, represented in Fig. 14 (Wheatstone's bridge), a galvanic element, or a galvanic battery B, and find that the current branches off in the direction of the arrows, so that the positive current likewise enters galvanometer G on both sides. If in such a combination the product of the resistances $R_1 R_3$ = the product of resistances $R_2 R_4$ the shunt currents passing through the galvanometer are of equal strength, and the needle remains at rest.

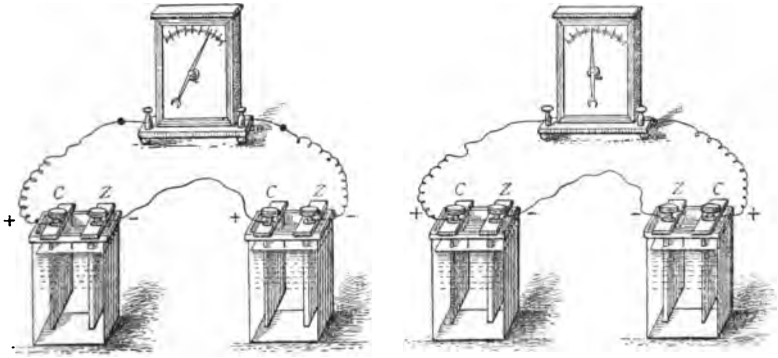

FIG. 13.

We now introduce in R_3 the wire whose resistance we want to measure and in R_4 an artificial resistance graduated in ohms (Fig. 14), which we alter till the galvanometer needle has returned to zero, then the products of the resistances $R_1 R_3 = R_2 R_4$.

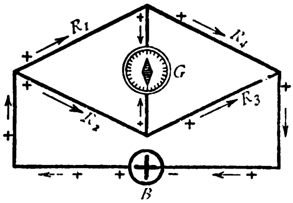

FIG. 14.

We have at the outset chosen wires R_1 and R_2 of equal resistance and therefore find $R_3 = R_4$, that is to say—resistance R_3, which is to be measured, can be simply read off on the graduated resistance scale.

Accurate measurements of very small resistances have sometimes to be made, and we must therefore describe the instrument used for this purpose ; it is

Siemens' Universal Galvanometer.

It is a combined Wheatstone bridge and galvanometer and is shown in Fig. 15. In a cylindrical glass case, whose lid can be screwed on, is an astatic needle galvanometer with gradiated disc, whose upper needle serves at the same time as pointer. The needle pair is suspended by a cocoon thread, which can be lowered or raised by means of a screw in the centre of the lid; by means of a lateral screw the arrest can be set in motion. The number of convolutions of the galvanometer is 1600 and its resistance about 100 ohms. Beneath the glass case is

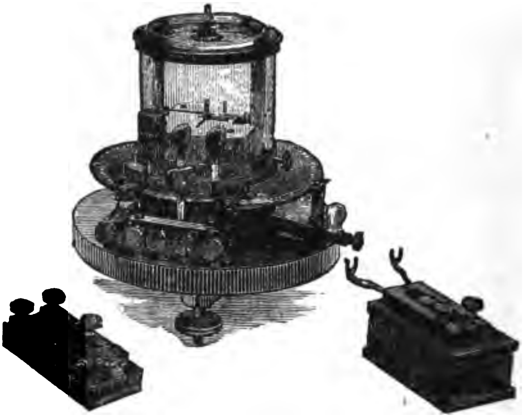

FIG. 15.

a circular graduated slate disc; the circumference of the disc is grooved, and a German silver wire placed in the groove surrounds the whole of the disc. The wire is calibrated in such a way that at equal length it has at all points the same resistance; it is divided into 300°. Let A mark the left-hand half and B the right-hand half of the graduated disk. An arm movable about the axis of the instrument, can be moved all along the German silver wire, and carries a running contact in form of a movable platinum coil pressing against the wire. Below the slate disc are the resistance coils made of German silver; their ends are in the usual manner connected to terminal screws and there is also the usual conection between them by means of plugs. A frame beneath the slate disc carries the binding screws I. to V. with a small Morse key between II. and V. and a plug between III. and IV.

The following is the method for determining an unknown resistance *x* by means of this instrument:

(*a.*) The needle of the small disc is brought to zero by turning the galvanometer round its vertical axis, the needle of course moving with perfect freedom.

(*b.*) An indicator *z* is by means of handle brought to zero of the scale of the slate disc.

(*c.*) A plug is inserted between the terminals marked III. and IV.

(*d.*) Two of the three holes 10, 100 and 1000 are plugged and the third is left open, according to the magnitude of the unknown resistance; if it is small, one of the holes, 10 or 100, is left open; if large, hole 1000 remains free.

(*e.*) The two terminals II. and IV. are connected to the extremities of the unknown resistance.

(*f*.) The two terminals I. and V. are connected with the two poles of a battery.

The connections being thus made, the battery current is sent through the system by pressing the Morse key. Let us suppose that a deflection of the needle to the right B of the instrument be the result. The indicator is then by means of the handle moved towards the side B of the instrument. If by this the deflection of the needle is increased, the indicator z is brought back to the other side A of the instrument beyond zero of the large scale, until the needle remains stationary at zero, when the Morse key is pressed down. The number of degrees indicated by z is then carefully read off, noting at the same time whether the reading is taken on side A or B of the instrument. The number read off is then referred to a previously constructed table, and the figure corresponding to this number, on being multiplied with the remaining resistance of the circuit, gives the unknown resistance. Let us suppose that the reading gives 50° on the side of A of the large scale, the resistance of the circuit being 100 units; we then have from the general formula $x = n \times \frac{150 + a}{150 - a}$;

where n is artificial resistance, x unknown resistance, and a the number of degrees read off on the side of A; and

$$x = n \times \frac{150 - a}{150 \times a},$$

when the reading is on the side of B; in our case,

$$x = 100 \times \frac{200}{100} = 200 \text{ units.}$$

Other instruments for measuring differences of potential are *Thomson's Potential Galvanometer and Siemens' Torsion Galvanometer*; their manipulation however requires a great deal of care and also theoretical knowledge, and their use is therefore restricted to scientific investigations. The ammeter of low resistance (Fig. 11) enables us, in direct connection, to measure the current at any point of the circuit, whilst the voltmeter of relatively high resistance, placed in a shunt between any two points of a circuit, allows of a direct measurement in volts of the difference of potential between these two points. The ratio of these two quantities—current and electromotive force—gives the resistance between these two points:

$$R = \frac{E}{C},$$

and thus we have a means to determine the resistance in any divisonal part of the circuit—in the voltaic arc or the incandescent filament respectively—without stopping or interfering in any way with the current, a matter of the greatest importance in electric lighting, where the resistance is constantly being changed by the action of the current. This result can also be obtained directly with

Ayrton and Perry's Ohmmeter.

The instrument is shown in Fig. 16, and consists, like the ammeter, of a coil carrying the main current actuating a needle. The needle is here brought back by an electromagnet wound with fine wire and not, as in the ammeter, by a permanent magnet; the connection of the electromagnet is the same as that of the coil of the voltmeter. The amount of deflection thus depends on the ratio of the currents in the magnet and in the coil respectively; that is, on the ratio of E. M. F. to the current, and therefore measures the resistance between the two points to which the electro-magnet is attached. By a convenient arrangement of details the deflection of the needle is made proportionate to the resistance.

It has been stated on p. 47 that the mechanical work expended in the dynamo is calculated from the formula CE × ·00181, according to which the mechanical work is dependent on the current C and the electromotive force

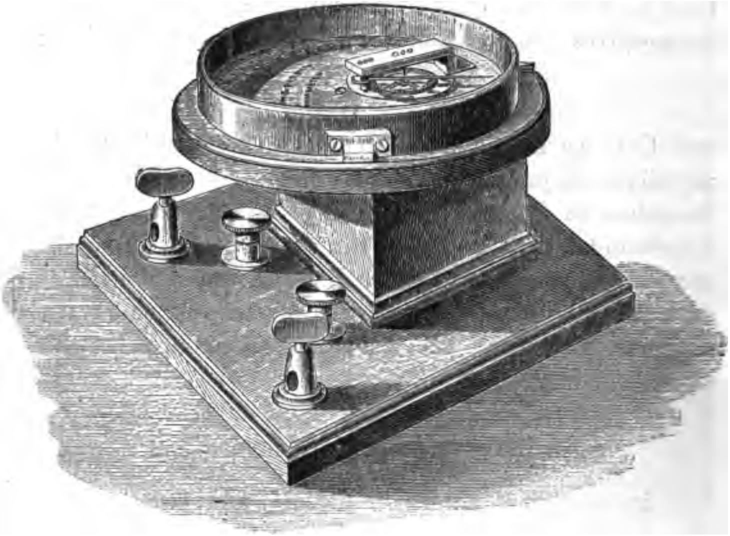

FIG. 16.—AYRTON AND PERRY'S OHMMETER.

E., which can easily be measured with the ohmmeter and voltmeter.

Ayrton and Perry have constructed an instrument *Electric Power Meter*, Fig. 17., for direct measurement of C and E (the latter for the two terminals of the lamp) in horse power, referring the illuminating power measured in candles to the mechanical efficiency of the arc and not to that of the motor driving the dynamo, (v. p. 47). Of this work 85 per cent. in the mean are converted into electricity (v. table, p. 48 value W : H.P.), and assuming that half of this work is wasted by heating the light circuit and dynamo respectively (v. p. 24), we have to reckon for every horse-power expended in the arc, 2½ mechanical horse-power of the machine, and this enables us by means of the above measurements to determine the illuminating power for every horse-power expended in the machine.

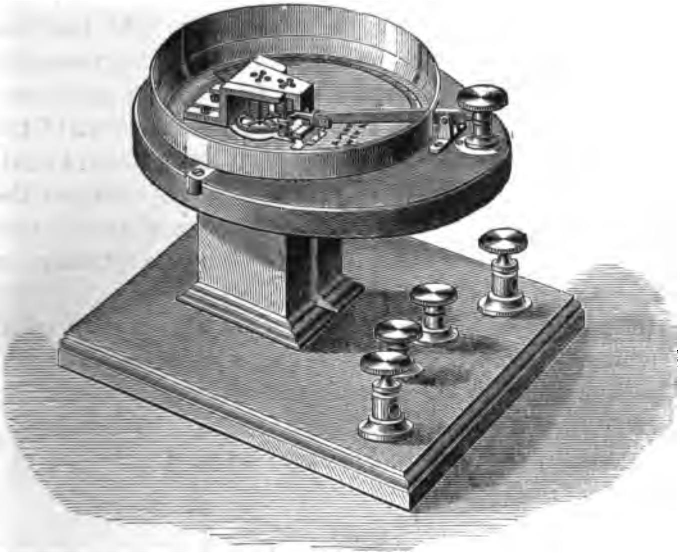

FIG. 17.

The latest form of the instrument shown in Fig. 17 employs a wheel and pinion and double spring, like the wheel and pinion ammeter and voltmeter. The outer and larger binding screws are for taking the wires which form part of the main circuit; the inner smaller binding screws for the finer shunt wires which are attached to that part of the circuit, the energy electrically expanded in which it is desired to measure. One or both springs can be employed, and so two very different grades of sensibility are possible; also a definite amount of angular set can be given to either, so that a small change in a large horse-power will cause a great change in the deflection of the pointer.

How to determine the resistance of a light machine when at rest we have shown on p. 60. Having measured the current C and electromotive force E, the resistance follows from Ohm's law, and even a measurement of the current alone, with the assistance of an interpolated known resistance, would suffice to measure the resistance of the machine when at work, if the E. M. F. were to remain constant, and not, as is the case with dynamos, dependent on the external resistance.

Supposing that for a dynamo driven at a certain speed a current, C, has been measured in a circuit whose resistance x is to be determined, and after interpolation of a known resistance R, without altering the number of revolutions, the current measured to be C, we get two equations:

$$C = \frac{E}{x}, \text{ and } C_1 = \frac{E}{x + R}$$

$$E = Cx;$$

$$C_1 = \frac{Cx}{x + R}; \; x = \frac{C_1 R}{C - C_1}.$$

Before leaving the subject of measurements we have to mention an apparatus belonging to the third class referred to on p. 53, and based on the chemical action of the current. The apparatus in question is only employed in such cases where electric light is supplied by a central station, there has been no call for it as yet in this country; but it is extensively used in the United States, where the Edison and other Companies are successfully working a number of central stations for public as well as for domestic lighting. A number of instruments have been patented for this purpose, amongst which for the sake of priority we will first mention

Edison's Current Meter.

The principle of action of the instrument depends upon the fact that the weight of metal deposited per unit of time, in an electro-plating bath by electrolysis, is proportioned to the quantity of electricity passing through it in the same period, or, in other words, to the strength of the current; and as the amount of the electro-deposition is equal at all points of a circuit, it follows that, by placing

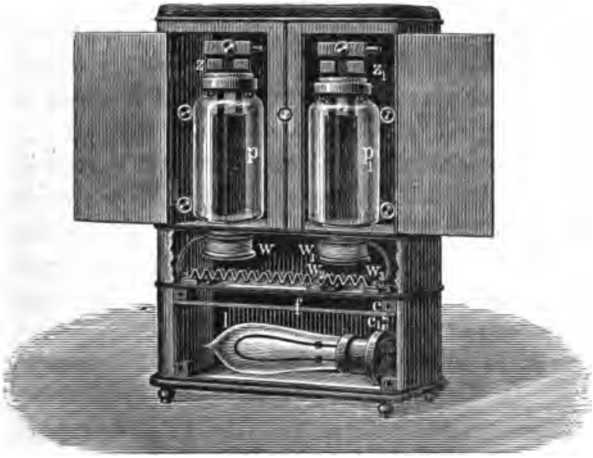

FIG. 18.—EDISON'S CURRENT METER FOR HOUSE SERVICE.

an electrolytic cell in any part of a circuit, the amount of electricity transmitted by the cell in a given time can be determined by observing the quantity of metal deposited within the same period. The apparatus employed by the Edison system in connection with the service of a house is illustrated in Fig. 18. *p* and p^1 are the two glass cells, hermetically closed by the stoppers Z, Z^1 and filled with a solution of zinc sulphate, in which is immersed a pair of amalgamated zinc plates. The two cells are precisely alike, but from the fact that the one cell is short-circuited by a shunt, having one fourth the resistance of the shunt by which the other is short-circuited, the quantity of electricity passing through the former in a unit of time is four times that which is transmitted by the other, and therefore, within a given period, the quantity of metallic zinc deposited on the receiving plate of one cell is four times that which is deposited on that of the other. The short-circuiting shunts are shown at w_2 and w_3, and consist of a corrugated band of German silver, of which the 12 corrugations towards the left of the figure constitute the shunt of the cell *p*, while the remaining four corrugations belong to the right-hand cell p^1. An ordinary Edison glow lamp *l* is thrown into the circuit whenever contact is made at the point c_1, and this is effected by the bending downwards of the compound expansion bar *f c*, which is so constructed and adjusted as automatically to throw the lamp into circuit whenever the temperature within the instrument falls below a certain point. The radiant heat from the lamp then raises the temperature of the air within the apparatus, until, by the upward curling of the compound bar, the lamp is again cut out of the circuit. *w* and w^1 are two compensating resistance coils of insulated copper wire, which are included in the branch circuit of the electrolytic cells, their object being to keep the resistance of the apparatus uniform under variations of temperature; for, as the resistance of the zinc solution within the cells is diminished by a rise of temperature, the quantity of electricity transmitted by it would be greater as the temperature was increased, unless this increase were compensated or neutralized. To effect this, a coil of copper wire is inserted in the circuit of each cell, and as the electrical resistance of copper increases with a rise of temperature, while that of the zinc solution diminishes, it is only necessary to make the length of the copper wire such that its resistance rises under an increase of temperature, as much as that of its corresponding cell diminishes, in order to compensate the apparatus for variations of temperature. The object of having two cells instead of one, is to enable the supplying company to keep a check upon its inspectors, and also to guard against fraud on the part of dishonest consumers; for while the left-hand division of the meter is accessible to ordinary inspectors, and in some cases to the consumers themselves, the right-hand portion is under the sole control of the company, through their superior inspectors, and the readings of the two cells should always be in the same proportion to one another. Again, the object of causing the one cell to deposit slower than the other is that, while the ordinary inspectors go their rounds once a month, the upper inspectors visit the meters once a quarter; the one cell is therefore depositing for four weeks between two inspections, while the other is in action for thirteen weeks before its plates are weighed again; and by causing the three months' cell to deposit slower than the one month cell, the amount deposited in each between any two inspections is more nearly equalised. The cells are removed every month and fresh ones substituted in their place; and, from the amount of zinc deposited, the consumer is charged so much per ampère of current passed through the meter per hour.

Edison has also constructed a more elaborate automatic meter, which is rather suited to the laboratory of the central station than to a house or factory installation, where it might soon be put out of order. The second apparatus, represented in Fig. 19, consists of two movable copper cylinders suspended to a balance beam, and placed inside of two similar cylinders of larger diameter, which have a fixed position in two vessels filled with a solution of copper sulphate. The working current passes through the copper cylinders of both vessels, and the copper is simultaneously deposited on the external cylinder of the one and the internal cylinder of the other vessel. This causes the movable cylinder of one vessel to sink down

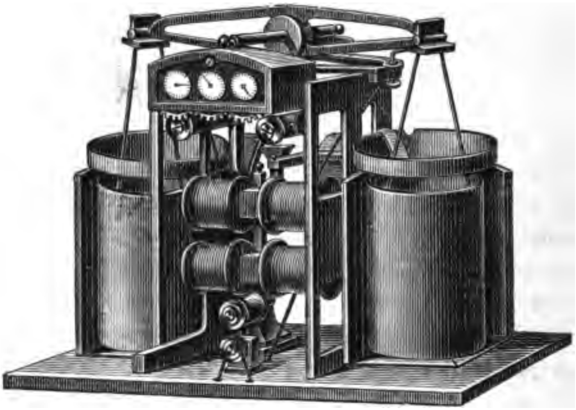

Fig. 19.—Edison's Current Meter for Central Station.

while the other rises, and as soon as the balance beam has assumed a certain low position, the direction of the current is altered, and reverse motion of the two interior cylinders ensues.

The above instruments measuring the quantity of current supplied by a central station can only be used in cases where, as in the Edison system, the E. M. F. at the place of consumption is kept nearly constant. If this is not the case, both current and electromotive force must be measured, for the simple reason that the payment of the consumer is determined by the electric work done, which is proportional to the product of the current and of the E. M. F.

A convenient instrument for this latter purpose is

Ayrton and Perry's Ergmeter.

This instrument consists of a good pendulum clock, the bob of the pendulum being formed of a high resistance coil (1000 ohms). Parallel to it, and fixed to the clock case is another coil of very low resistance. The latter is traversed by the main current, while a shunted current flows through the former. The connection of this shunted current must be made at the spot where the service leads for the supply of a building branch off from the main conductor, so that in the windings of the pendulum the E. M. F. of the main conductor of the buildings finds an expression. With such an arrangement, the latter E. M. F. as well as the strength of the main current, act in common on the clockwork; the direction of the current in both coils is such as to retard the action of the pendulum, and the clock consequently loses as long as the current passes. This loss is nearly proportional to the two factors of work.

Another instrument for measuring the quantity of electricity supplied to the consumer is

*Dr. Aron's Electricity Meter.**

It consists of a pendulum clock, the rate of acceleration of which, in comparison to standard time, is exactly proportional to the strength of the current. The bob of the pendulum is replaced by a cylindrical magnet, and below it is placed the coil through which the current flows. The direction of the current is such as to draw the magnet down, increasing, so to speak, the influence of gravity, and thus accelerating the clock. In order that the acceleration may be exactly proportional to the current, it is important to employ for the magnet steel of a certain hardness. The temporary magnetisation it receives from the current will thus favour a quickened motion of the pendulum throughout a wide range of current strength, which renders the instrument exceedingly accurate. The advantages of this meter over the chemical meter of Edison are obvious. In the latter the indications vary with the temperature, and the weighing of the plates requires the utmost care. It has also happened that the plates have been short circuited by the deposit of zinc, and during the time the plates are dried and weighed, the meter is out of action. All these disadvantages are overcome in Dr. Aron's meter. The reading does not interrupt the action of the instrument, and errors committed in single readings eliminate each other when added up to arrive at the total quantity of electricity passed during an extended period. The Municipality of Berlin have, after comparative experiments with Edison's and Aron's meter, finally adopted the latter.

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* From *Electrician*, Sept. 4, 1885.

In one of these instruments, which had been in use for several months, and designed for a maximum current of 200 ampères, an acceleration of one hour corresponded to 1356 ampère hours (a current of 1356 ampères during 1 hour, or of 1 ampère during 1356 hours) or 2260 lamp hours (current feeding 2260 lamps for one hour, or one lamp for 2260 hours), each lamp hour being equivalent to a current of ·6 ampère flowing for one hour. With a current of about 100 ampères the clock is accelerated about 20 minutes in 4—5 hours. It will be evident that with such a large rate of advance any slight error in the clock itself or in the reading becomes quite insignificant. The following table from the records of the above instrument will show the method of booking.

1885.	Standard Time.	Meter time.	Total difference.	Last difference.	Ampère hours.	Lamp hours.	Value ·4 mark (shillings) per lamp hour.
July 25.	4^{35}	10^{55}	6^{20}	1^{32}	2088	3480	139·21 mark.
Aug. 1.	11^{43}	7^{35}	7^{52}				

For arc light installations working with a constant current a similar instrument is used registering volt-hours. It is suitable for a pressure not exceeding 2000 volts. One hour acceleration corresponds to 41,022 volt hours, and if there are 25 arc lights in series, the rate of advance in 5 hours is about ten minutes. The booking is similar to the example just given. For instance:

1885.	Standard Time.	Meter Time.	Total difference.	Last difference.	Volt hours.	Lamp hours.	Value ·75 mark (shillings) per lamp hour.
Aug. 20.	2^{28}	12^{45}	10^{17}	$0^{10\cdot5}$	7179	156	116 mark.
Aug. 21.	10^{75}	8^{35}	$10^{27\cdot5}$				

These meters must be periodically wound up, just as an ordinary clock; if, however, it is desirable to have a self-winding clock, Dr. Aron adds to his meter a dry-cell and an electro-magnetic apparatus which keeps the clock going without any attention whatever being required. Such a clock has been going for 9 months without having been touched.

Regulations made by the Board of Trade restrict in this country the differences of potential within certain limits, and the *Brush Company* taking into account these regulations have constructed an ampère-meter of very simple form. A clock supplies the motive power for the registration of the current consumption. The clockwork, by means of a lever, actuates the pointer of a counter, which works the faster the lower the position of the lever. The latter is connected to the iron core of a wire coil, through which the working current flows, and the iron core is lowered and raised in proportion to the strength of the current. The more lamps are burning in a circuit the lower stands the iron core and the quicker moves the counter, whilst the latter is at rest when the iron core has completely receded in consequence of not being traversed by any current. The motion of the iron core is, by a tracing pin attached to it, marked in the form of a curve, on an endless strip of paper, passing over three rollers. The whole apparatus is enclosed in a glass case, and the dial of the clock, the graduated disc of the counter and a part of the latest graphic representation of current consumption, are visible on the outside; the apparatus therefore not only registers the current, but also replaces a clock.

§ 7. PHOTOMETRIC METHODS.

All the methods for electrical measurements, which have been treated in the preceding chapter lead up to one final question, namely: *how much light can be obtained by a certain amount of electrical work.* It is clear, therefore, that it must be of the highest importance to ascertain by accurate measurements the illuminating power of a light centre, inasmuch as this power is an expression of the efficiency of the dynamo, whose sole object is the production of light under the most favourable conditions of economy. All methods of electrical measurements with the help of the instruments now at our disposal are based on strictly scientific principles, and lead to results whose accuracy cannot be disputed. It is not so with our present methods of ascertaining the quantity of light given out by a certain centre. The luminous effect of a source of light is an effect produced by the light rays on our eyes, which effect causes a certain sensation called light. The eye alone therefore can finally decide the question of illuminating power, and the results obtained must naturally more or less depend upon the aptitude of the individual observer for this special mode of research. It has been suggested, and various methods have been based upon this suggestion, to replace the physiological effect of a source of light on the retina by a chemical effect, forgetting that such methods could only be accurate where the composition of the spectrum of the source of light is perfectly identical with that of the light chosen as the unit of comparison.

All photometric methods are not absolute measurements but comparative ones, and it is of great importance to agree upon a common unit of comparison; this unit in France is the Carcel lamp, a moderator lamp with a wick 30 mm. in width, in which pure colza oil is burned at 40 mm. height of flame; in this country and in Germany, a so called "standard candle" is used as unit of light. The English standard candle is a sperm candle burning 120 grains per hour; the German is a paraffin candle of 20 mm. diameter and 50 mm. height of flame (1 Carcel = 9·5 English candles).

It has been lately proposed to use as unit of measurement the heating effect of a constant current flowing through a conductor of definite size and shape. *Louis Schwendler*, of Calcutta, has for this purpose proposed a strip of platinum ·017 mm. thick, and cut out in the form of a horse-shoe. Schwendler has shown that with a constant current the intensity of glow of the platinum foil is exceedingly constant.

The Paris International Conference of 1881 has adopted as unit of white light, that quantity of light which is given off by 1 square centimetre of pure melted platinum at the temperature of congelation. The quantity of coloured light of a certain tint contained in this quantity of white light is the unit of coloured light of that certain tint. Werner Siemens* has constructed a lamp for photometric methods based on a very similar unit, namely, that of pure platinum in melting condition, instead of melted platinum at the point of congelation. The platinum strip, 5–6 mm. wide, is placed in a small metal box behind the narrowest ending of a conical opening of exactly 1 square centimetre area; the platinum strip is brought to incandescence by a number of galvanic elements which are so arranged that the current strength can be slowly raised to the melting point of the platinum. The light given off by the platinum strip at the moment of fusion is then exactly $\frac{1}{10}$ of the unit adopted by the Paris Conference. By a simple mechanism a fresh strip of platinum can be introduced in the box and the experiment repeated without loss of time. In practice it will be found advantageous to use for measurement incandescent lamps whose illuminating power has from time to time been accurately determined by means of this platinum photometer. A standard candle (v. p. 78) has been found ·07 of the unit adopted by the Conference.

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* *Electrotechnische Zeitschrift*, 1884, No. VI. p. 244.

In all photometric measurements we must never lose sight of the fact that the intensity of the light varies according to the angle at which the light is thrown on the measuring apparatus; we must, therefore, always arrange the light in such a way that its rays fall on the plane to be illuminated at a certain definite angle.

The simplest and most extensively used instrument is *Bunsen's Photometer*. It consists of a sheet of paper with an oiled and consequently transparent circle in its centre. The paper is placed between two mirrors at equal angles to both, so that the image of the oiled spot can be seen at the same time in both mirrors. By placing on either side of the photometer a source of light, the image, according to the different intensity of these sources, appears brighter in one mirror and darker in the other; the more intense source producing the brighter, the less intense source the darker image. The photometer is now moved forwards and backwards on a graduated ruler, placed between the sources of light, until the images appear equally bright. As soon as this condition is fulfilled the photometer is equally illuminated by both sources, and their illuminating power is then in direct proportion to the square of their distances from the photometer. These distances are ascertained by direct reading of the graduated ruler. These measurements must of course be made in a completely darkened room, so that no other light beside the two sources which are to be compared can act on the photometer.

A photometer based on the above-mentioned chemical action of light, and which can therefore only be used for comparing sources of light of equal spectral composition, is *Siemens' Selenium Photometer.* It consists of a brass tube enclosing a selenium cell (a thin metallic disc coated with selenium) placed on a support which is attached to a graduated ruler, on which a standard candle can be moved backwards and forwards. The selenium cell is connected to a galvanometer, and alternately exposed to the standard candle, and to the source of light to be measured; at the same time the normal candle is displaced on the ruler until the deflections of the galvanometer are equal. The distance of the standard candle from the selenium cell, which can be read off on the scale, gives the proportion of the standard candle to the source of light to be measured.

If a very intense light (for instance, an arc light of several thousand candles) has to be measured, the light source must be placed at considerable distance from the ordinary Bunsen photometer, otherwise the length of the ruler would not suffice for the necessary displacements of the screen. This class of tests, therefore, when made with the ordinary photometer requires a dark room of very large dimensions, and even then the source of light being far apart from the instrument the accuracy of the observations is seriously impaired by the different condition of the atmosphere, that is to say, by the accumulation of solid particles suspended in the air, which, of course, is the larger the greater the distance of the source of light from the instrument.

Ayrton and Perry's Dispersion Photometer helps us over this difficulty; it is represented in its latest form in Fig. 20. The instrument is placed on a tripod stand E, to which it is fixed in such a manner as to allow its adjustment in a horizontal direction. The silvered plane mirror H can be placed at different angles to the incident light rays, and carries a pointer moving over a graduated disc G, which shows the deflection of the rays from the horizontal. The mirror throws the rays on a concave lens fixed to a movable wooden frame C, and, by means of this lens, on the paper screen B; a short black stick A, throws its shadow on the screen. In order to exactly direct the light on the centre of the screen, a slide with a small

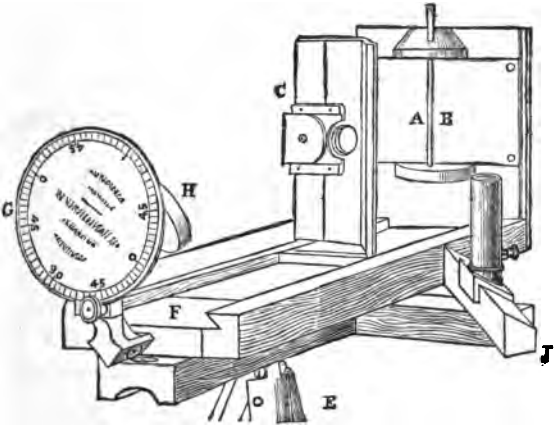

FIG. 20.—AYRTON AND PERRY'S DISPERSION PHOTOMETER.

opening is used. The standard candle placed in the movable holder D causes a second shadow of the stick A, alongside of that produced by the electric light. The lens with its movable frame C, is now displaced until both shadows show the same intensity when being observed first through a red and then through a green glass. Both glasses are fixed to a convenient part of the instrument. The displacement is read off on a fixed scale.

Let e be the distance of the lens, e_1 that of the standard candle, and E that of the electric light from the paper screen (E = variable distance of the light from the mirror + constant distance of the centre of the mirror from the screen), further let b be the focal length of the lens and L the illuminating power in standard candles; then:

$$\sqrt{L} = \frac{E - e}{e_1}\left[1 + e\left(\frac{1}{b} + \frac{1}{E - e}\right)\right]; \text{ or}$$

$$L = \frac{1}{e_1^2}\left(E + \frac{e(E - e)}{b}\right)^2.$$

L only represents the light effect measured in one direction; the total illuminating power is assumed to be $= L + \frac{L}{2}$. In order to measure the light given out in a horizontal direction, the electric light, after going through the manipulations described above, is placed in a different position to the mirror (moving it through L a), and the latter turned so far round its horizontal axis that its central rays exactly fall on the centre of the lens. In this case E is distance e_2 from the centre of the mirror to the paper screen + the vertical distance e_3 from the centre of the mirror to the centre of the arc × sec. a or

$$E = e_2 + e_3 \text{ sec. } a.$$

This value of E introduced into the above equation gives L for a horizontal direction.

The dispersion photometer allows of a measurement of a very intense light being taken in a small room.

§ 8. ARRANGEMENT OF LEADS AND LAMPS. INSTALLATIONS.

Wherever dynamos and lamps, as for instance, in factories, theatres, &c., are not too far apart from each other, the installation is very simple. One conductor is used for the whole circuit, for lead as well as for return. The material of the conductor is almost exclusively copper, on account of its high conductivity (silver 100; copper 77·3). As regards the size of wire used, the Board of Trade regulations prescribe 1 square inch for a current of 1000 ampères. If stronger currents are sent through the conductors a large fraction of the whole heat generated by the current is wasted, and the wires become a source of danger to inflammable objects in their close proximity. Complete insulation of all conductors is a condition *sine qua non* in closed spaces. The insulating material is generally caoutchouc, a bad conductor of heat as well as of electricity. Where underground cables are used, or where the cables pass through water, the copper conductor, generally formed of a certain number of fine wires twisted so as to give it the requisite strength (stranded wire), is first covered with one or two coatings of caoutchouc; the latter material is surrounded by a layer of tarred hemp or jute, and finally enclosed in an iron pipe formed of stout twisted iron wire. In this latter case the close proximity of telephone or telegraph wires must, for the sake of the latter, be carefully avoided, as the strong lighting currents would greatly interfere with their working.

The cost of the copper conductors forms a serious item in an electric light installation. Only to mention one instance, where the light machines were at a distance of 150 yards of the lighted area, the whole cost of plant was £3,000, including £560 for copper conductors, or nearly one-fifth of the whole expense. It is, therefore, of the utmost importance to select a wire of proper cross section, not too thin on the one hand to cause waste of heat, or give rise to danger of conflagration, and not too stout on the other hand to necessitate too large an outlay. Sir William Thomson has proposed to give to the conductors such dimensions that the interest of the capital represented by the wires may favourably compare with the expense caused by waste of heat in these wires. Basing his calculation on certain figures (1 ton of copper cost £70, average working hours 12, specific weight of copper 8·9, cost of one horse-power per annum £10), he arrived at the result, that the cross section of the conductors measured in square centimetres must be about $\frac{1}{50}$ of the current expressed in ampères under the most favourable conditions of economy. So, for instance, a current of 21 ampères would require a conductor of ·4 square centimetre cross section.

The table on the following four pages will show the size and weight of wire which must be employed to carry with safety a current of a certain strength.

In determining the cross section of the conductor, the length of the circuit must be considered as well as the strength of the current, because the resistance increases in direct proportion to the length of circuit. In many cases it will be found more profitable to lose part of the current,

Table showing the Diameter, Weight, Resistance and Size in B. W. G. of Copper Conductors for a certain Current.

Safe current in ampères.	Diameter of Conductor in inches.	Ounces per yard.	Pounds per mile.	Resistance in ohms.		B. W. G. No.
				Per yard.	Per mile.	
1	·05582 ; $\frac{19}{\cdot00358}$	·0363637	4	·1302572	229·253	27 ; $\frac{19}{43}$
2	·02501 ; $\frac{19}{\cdot00565}$	·0909091	10	·0521029	91·701	22 ; $\frac{19}{38}$
3	·03356 ; $\frac{19}{\cdot00759}$	·1636364	18	·028946	50·945	20 ; $\frac{19}{36}$
4	·04033 ; $\frac{7}{\cdot01706}$	·2181818	26	·0200395	35·269	18 ; $\frac{7}{27}$
5	·04680 ; $\frac{7}{\cdot01747}$	·3181818	35	·0148875	26·203	18 ; $\frac{7}{26}$
6	·05306 ; $\frac{7}{\cdot01981}$	·4090909	45	·0115785	20·378	17 ; $\frac{7}{25}$
7	·05866 ; $\frac{7}{\cdot02190}$	·500000	55	·0094729	16·672	16 ; $\frac{7}{24}$
8	·06426 ; $\frac{7}{\cdot02399}$	·600000	66	·0078944	13·894	15 ; $\frac{7}{23}$
9	·06941 ; $\frac{7}{\cdot02591}$	·700000	77	·0067666	11·909	15 ; $\frac{7}{22}$
10	·07420 ; $\frac{7}{\cdot02770}$; $\frac{19}{\cdot01677}$	·800000	88	·0059208	10·421	14 ; $\frac{7}{22}$; $\frac{19}{26}$
15	·09752 ; $\frac{7}{\cdot03641}$; $\frac{19}{\cdot02204}$	1·3818181	152	·0034279	6·0333	12 ; $\frac{7}{19}$; $\frac{19}{24}$
20	·11812 ; $\frac{7}{\cdot04410}$; $\frac{19}{\cdot02670}$	2·0272727	223	·0023365	4·1122	10 ; $\frac{7}{18}$; $\frac{19}{22}$
25	·13701 ; $\frac{7}{\cdot05115}$; $\frac{19}{\cdot03079}$	2·727272	300	·0017370	3·0571	9 ; $\frac{7}{17}$; $\frac{19}{21}$
30	·15480 ; $\frac{7}{\cdot05779}$; $\frac{19}{\cdot03499}$	3·4818181	383	·0013604	2·3943	8 ; $\frac{7}{16}$; $\frac{19}{20}$
35	$\frac{7}{\cdot06402}$; $\frac{19}{\cdot03876}$	4·272727	470	·0011086	1·511	$\frac{7}{16}$; $\frac{19}{19}$
40	$\frac{7}{\cdot07005}$; $\frac{19}{\cdot04239}$	5·1090909	562	·0009271	1·6317	$\frac{7}{15}$; $\frac{19}{18}$
45	$\frac{7}{\cdot07569}$; $\frac{19}{\cdot04583}$	5·9727272	657	·0007931	1·3959	$\frac{7}{14}$; $\frac{19}{18}$
50	$\frac{7}{\cdot08125}$; $\frac{19}{\cdot04919}$	6·8818181	757	·0006883	1·2114	$\frac{7}{13}$; $\frac{19}{17}$

Safe current in ampères.	Diameter of Conductor in inches.	Ounces per yard.	Pounds per mile.	Resistance in ohms.		B. W. G. No.
				Per yard.	Per mile.	
55	$\frac{7}{\cdot08655}$; $\frac{19}{\cdot05240}$	7·8090909	859	·0006066	1·0676	$\frac{7}{13}$; $\frac{19}{17}$
60	$\frac{7}{\cdot09173}$; $\frac{19}{\cdot05554}$	8·7727272	965	·0005400	·9540	$\frac{7}{13}$; $\frac{19}{17}$
65	$\frac{7}{\cdot09678}$; $\frac{19}{\cdot05860}$	9·7636363	1074	·0004822	·8539	$\frac{7}{12}$; $\frac{19}{16}$
70	$\frac{7}{\cdot10165}$; $\frac{19}{\cdot06155}$	10·727272	1185	·0004397	·7739	$\frac{7}{12}$; $\frac{19}{16}$
75	$\frac{7}{\cdot10643}$; $\frac{19}{\cdot06444}$	11·8090909	1299	·0004011	·7059	$\frac{7}{11}$; $\frac{19}{15}$
80	$\frac{7}{\cdot11112}$; $\frac{19}{\cdot06728}$	12·8727272	1416	·0003680	·6477	$\frac{7}{11}$; $\frac{19}{15}$
85	$\frac{7}{\cdot11569}$; $\frac{19}{\cdot07005}$	13·9545454	1535	·0003395	·5975	$\frac{7}{11}$; $\frac{19}{15}$
90	$\frac{7}{\cdot12021}$; $\frac{19}{\cdot07278}$	15·0636363	1657	·0003145	·5535	$\frac{7}{10}$; $\frac{19}{14}$
95	$\frac{7}{\cdot12462}$; $\frac{19}{\cdot07546}$	16·1909090	1781	·0002926	·5150	$\frac{7}{10}$; $\frac{19}{14}$
100	$\frac{7}{\cdot12896}$; $\frac{19}{\cdot07808}$	17·3363636	1907	·0002733	·4810	$\frac{7}{9}$; $\frac{19}{14}$
110	$\frac{7}{\cdot13742}$; $\frac{19}{\cdot08319}$	19·60000	2156	·0002407	·4236	$\frac{7}{9}$; $\frac{19}{13}$
120	$\frac{7}{\cdot14560}$; $\frac{19}{\cdot08816}$	22·10000	2431	·0002144	·3773	$\frac{7}{8}$; $\frac{19}{13}$
130	$\frac{7}{\cdot15358}$; $\frac{19}{\cdot09299}$	24·5909090	2705	·0001927	·3391	$\frac{7}{8}$; $\frac{19}{12}$
140	$\frac{19}{\cdot09770}$; $\frac{37}{\cdot06970}$	27·1454545	2986	·0001745	·3071	$\frac{19}{12}$; $\frac{37}{15}$
150	$\frac{19}{\cdot10231}$; $\frac{37}{\cdot07298}$	29·7636363	3274	·0001592	·2792	$\frac{19}{12}$; $\frac{37}{14}$
160	$\frac{19}{\cdot10680}$; $\frac{37}{\cdot07619}$	32·4363636	3568	·0001461	·2571	$\frac{19}{11}$; $\frac{37}{14}$
170	$\frac{19}{\cdot11122}$; $\frac{37}{\cdot07933}$	35·1727272	3869	·0001347	·2371	$\frac{19}{11}$; $\frac{37}{14}$
180	$\frac{19}{\cdot11553}$; $\frac{37}{\cdot08241}$	37·9545454	4175	·0001248	·2198	$\frac{19}{10}$; $\frac{37}{13}$
190	$\frac{19}{\cdot11977}$; $\frac{37}{\cdot08544}$	40·7090909	4478	·0001162	·2045	$\frac{19}{10}$; $\frac{37}{13}$
200	$\frac{19}{\cdot12394}$; $\frac{37}{\cdot08841}$	43·6818181	4805	·0001085	·1910	$\frac{19}{10}$; $\frac{37}{13}$

Safe current in ampères.	Diameter of Conductor in inches.		Ounces per yard.	Pounds per mile.	Resistance in ohms.		B. W. G. No.
					Per yard.	Per mile.	
210	$\frac{19}{\cdot12804}$;	$\frac{37}{\cdot01933}$	46·6181818	5128	·0001016	·1788	$\frac{19}{10}$; $\frac{37}{13}$
220	$\frac{19}{\cdot13207}$;	$\frac{37}{\cdot09421}$	49·600000	5456	·0000953	·1677	$\frac{9}{9}$; $\frac{37}{12}$
230	$\frac{19}{\cdot13604}$;	$\frac{37}{\cdot09704}$	52·6272727	5789	·0000900	·1584	$\frac{19}{9}$; $\frac{37}{12}$
240	$\frac{19}{\cdot13996}$;	$\frac{37}{\cdot09984}$	55·700000	6127	·0000851	·1498	$\frac{19}{9}$; $\frac{37}{12}$
250	$\frac{19}{\cdot14381}$;	$\frac{37}{\cdot10258}$	58·8090909	6469	·0000806	·1419	$\frac{19}{9}$; $\frac{37}{12}$
260	$\frac{19}{\cdot14757}$;	$\frac{37}{\cdot10527}$	61·9272727	6812	·0000765	·1346	$\frac{19}{8}$; $\frac{37}{11}$
270	$\frac{19}{\cdot15133}$;	$\frac{37}{\cdot10795}$	65·1181818	7163	·0000728	·1281	$\frac{19}{8}$; $\frac{37}{11}$
280	$\frac{19}{\cdot15510}$;	$\frac{37}{\cdot11064}$	68·4090909	7525	·0000693	·1220	$\frac{19}{8}$; $\frac{37}{11}$
290	$\frac{19}{\cdot15877}$;	$\frac{37}{\cdot11320}$	71·6818181	7885	·0000661	·1163	$\frac{19}{8}$; $\frac{37}{11}$
300	$\frac{37}{\cdot11585}$;	$\frac{49}{\cdot10019}$	75·000000	8250	·0000632	·1112	$\frac{37}{11}$; $\frac{49}{12}$
310	$\frac{37}{\cdot11841}$;	$\frac{49}{\cdot10240}$	78·3545454	8619	·0000605	·1065	$\frac{37}{10}$; $\frac{49}{12}$
320	$\frac{37}{\cdot12094}$;	$\frac{49}{\cdot10459}$	81·9363636	8991	·0000580	·1021	$\frac{37}{10}$; $\frac{49}{11}$
330	$\frac{37}{\cdot12345}$;	$\frac{49}{\cdot10676}$	85·1636363	9368	·0000557	·0982	$\frac{37}{10}$; $\frac{49}{11}$
340	$\frac{37}{\cdot12593}$;	$\frac{49}{\cdot10890}$	88·6181818	9748	·0000535	·0942	$\frac{37}{10}$; $\frac{49}{11}$
350	$\frac{37}{\cdot12839}$;	$\frac{49}{\cdot11103}$	92·3909090	10133	·0000515	·0906	$\frac{37}{9}$; $\frac{49}{11}$
360	$\frac{37}{\cdot13082}$;	$\frac{49}{\cdot11313}$	95·636363	10520	·0000496	·0873	$\frac{37}{9}$; $\frac{49}{11}$
370	$\frac{37}{\cdot13323}$;	$\frac{49}{\cdot11592}$	99·200000	10912	·0000478	·0841	$\frac{37}{9}$; $\frac{49}{11}$
380	$\frac{37}{\cdot13562}$;	$\frac{49}{\cdot11729}$	102·7909090	11307	·0000461	·0811	$\frac{37}{9}$; $\frac{49}{10}$
390	$\frac{37}{\cdot13799}$;	$\frac{49}{\cdot11933}$	106·4090909	11705	·0000446	·0785	$\frac{37}{9}$; $\frac{49}{10}$
400	$\frac{37}{\cdot14034}$;	$\frac{49}{\cdot12137}$	110·0636363	12107	·0000431	·0759	$\frac{37}{9}$; $\frac{49}{10}$

Safe current in ampères.	Diameter of Conductor in inches.	Ounces per yard.	Pounds per mile.	Resistance in ohms.		B. W. G. No.
				Per yard.	Per mile.	
410	$\frac{37}{\cdot14267}$; $\frac{49}{\cdot12338}$	113·7454545	12512	·0000417	·0734	$\frac{37}{9}$; $\frac{49}{10}$
420	$\frac{37}{\cdot14498}$; $\frac{49}{\cdot12538}$	117·4636363	12921	·0000404	·0711	$\frac{37}{8}$; $\frac{49}{10}$
430	$\frac{37}{\cdot14727}$; $\frac{49}{\cdot12736}$	121·2090909	13333	·0000391	·0688	$\frac{37}{8}$; $\frac{49}{10}$
440	$\frac{37}{\cdot14938}$; $\frac{49}{\cdot12918}$	124·9818181	13748	·0000379	·0667	$\frac{37}{8}$; $\frac{49}{9}$
450	$\frac{37}{\cdot15180}$; $\frac{49}{\cdot13128}$	128·7818181	14166	·0000368	·0648	$\frac{37}{8}$; $\frac{49}{9}$
460	$\frac{37}{\cdot15404}$; $\frac{49}{\cdot13322}$	132·6090909	14587	·0000358	·0630	$\frac{37}{8}$; $\frac{49}{9}$
470	$\frac{37}{\cdot15627}$; $\frac{49}{\cdot13514}$	136·4727272	15012	·0000347	·0611	$\frac{37}{8}$; $\frac{49}{9}$
480	$\frac{37}{\cdot15848}$; $\frac{49}{\cdot13705}$	140·3545454	15439	·0000338	·0595	$\frac{37}{8}$; $\frac{49}{9}$
490	$\frac{49}{\cdot13895}$; $\frac{133}{\cdot08409}$	144·2636363	15869	·0000329	·0579	$\frac{49}{9}$; $\frac{133}{13}$
500	$\frac{49}{\cdot14083}$; $\frac{133}{\cdot08523}$	148·2090909	16303	·0000320	·0563	$\frac{49}{9}$; $\frac{133}{13}$

The diameter of a single conductor in inches is only given as far as 30 ampères, for the simple reason that it is not only advisable, but almost necessary, for reasons which are mentioned on p. 317, to use a number of stranded wires of smaller diameter instead of a single large wire. The numerators of the fractions in the second column express the number of strands, and the denominators the size of wires in inches.

Pure copper weighs 555 lbs. per cubic foot. The resistance of ·001 inch at 60° Fahr., according to Dr. Matthiesen, = 10·32311 ohms. The resistance of copper varies with the temperature at about ·38 per cent. per degree Centigrade, or ·21 per cent. per degree Fahrenheit.

To convert	Inches to millimètres	multiply by ..	25·3994
	Feet to mètres	„ ..	·3048
	Yards to mètres	„ ..	·9144
	Miles to kilomètres	„ ..	1·6093
	Pounds to kilogrammes	„ ..	·45359

1 statute mile = 1760 yards, or 5280 feet.

through an increase of resistance in the circuit, than to employ a wire of larger cross section. Individual requirements and special considerations must decide the choice of the expedient to be adopted.

For larger installations, such as the lighting of railway-stations, streets, etc., where, as a rule, the dynamos are at a considerable distance from the lamps, and where several circuits branch off from the machine room, distinct arrangements must be made for connection within the machine shed, and for leads in the lighted area, the connection between the lamps, and a common return wire to the light machine.

Inside the machine shed and for connection of the lamps between each other, insulated wires of sufficient flexibility are chosen; the first consideration in the selection of outside leads is high conductivity, and the more so the longer the circuit. Several insulated wires are for this purpose generally joined into a cable, and this latter attached to supports either fixed to the building, or, when this is not feasible, to independent supports. In some cases the leads pass underground or through water.

When cables are inserted in an iron pipe, no special return wire need be employed; the iron mantle can serve as such, without requiring any insulation. In most cases the authorities allow the use of gas or water pipes for this purpose, provided the passing currents have not too high a tension. In some cases earth returns have been adopted, but this expedient is not to be recommended, because on the one hand, on using special earth plates, the distributing area cannot be made large enough, and on the other hand, they introduce resistance and necessitate extra precautions in working.

If a number of dynamos are used to supply several light-circuits, a *switch board* is placed near the machines, the whole of the wire connections are attached to this board, so that by a simple manipulation (insertion of a metal plug or turning a handle), the different branches can be introduced into the circuit, or cut out from it, or connected to the light machines, according to the requirements of the case.

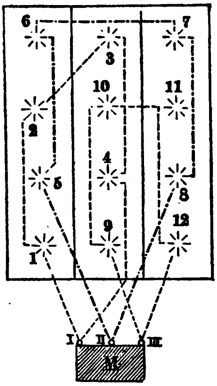

FIG. 21.—DIAGRAM SHOWING CONNECTION OF LAMPS AND MACHINE.

It is of course impossible to lay down hard and fast rules for the arrangement of conductors and lamps, and even if this were possible the task would not come within the scope of this book. But in order to afford a clear insight into the connection between dynamos, lamps and conductors in a practical light circuit, we are going to consider some special cases, which will illustrate, much more effectually than general observations, the one important fact, that special requirements necessitate special arrangements. Let us suppose several circuits branching off from one dynamo, with several lights in each circuit; we then arrange the leads that lamps in different rooms, or different parts of one large room, are supplied by the same circuit, as shown in Fig 21. Three circuits, I., II., III. branch off from the dynamo M., four lamps being placed in each circuit—lamps 1–4 in circuit I., 5–8 in circuit II., and 9–12 in circuit III. This arrangement offers the double advantage, that the extinction of the lamps in one circuit, does not leave one particular room or part of a room completely in the dark, and also allows of the cutting out of individual circuits during such periods of time in which the full illuminating power is not required. The advantage of similar arrangements is self-evident, and fully compensates for the larger expense they entail in the material of the conductors.

Arc Lamp Installations.

The construction of arc lamps permitting multiplication of light is due to Hefner von Alteneck. Single light or *monophotal* arc lamps present this common characteristic feature, that the electro-magnetic system which produces the adjustment of the distances of the carbon is traversed by the main current, the variations of strength of the current, cause the approach or withdrawal of the carbons; in other words they are adjusted for a constant current. This property renders the arrangement of a number of these lamps in one circuit impossible, simply because they are not independent of changes of resistance in the external circuit, and every variation of current in the arc of one lamp must necessarily disturb the mechanism of a second lamp in the same circuit. The *polyphotal*, or multiple arc lamp, constructed by Hefner von Alteneck, and all lamps constructed since, after the same type, are adjusted for a constant resistance of the arc, and this is effected by placing the regulating apparatus in a shunt of the main current instead of this current itself. The approach of the carbons is brought about by a thin wire coil placed in a shunt, while the withdrawal of the carbons is caused by a coil of stout wire placed in the main circuit. Whilst, therefore, in monophotal lamps, the approach of the carbons is produced by mechanical means, independent of electrical methods, this result is in differential lamps obtained by an electrical effect, namely, by the attraction of the shunt coil.

Fig. 22 gives a diagram of the circuits through one of these lamps.

R_1 is a coil of stout, R_2 a coil of thin, wire; both are connected together and to the terminals of the lamp circuit; rod SS, which is attached to one end of the lever, c_1c_2 movable about *d*, rises or descends within these two coils, and with it rises or descends the upper carbon k_1, which is carried by the other end of lever c_1c_2. The free end of coil R_1 leads to the axis of rotation of lever c_1c_2, whilst the free end of coil R is by wire connected to the holder of the lower carbon. The combined weight of the two carbons is as nearly as possible compensated by that of rod SS, so that lever c_1c_2 is in equilibrium, whatever the position of the carbons. The regulation of the arc is therefore solely effected by the difference of effect, produced by the electric current on the two coils R_1 and R_2. Now, the fine wire coil being placed in a shunt of the main current supplying the arc, the current of these two branches is inversely proportional to their respective resistances.

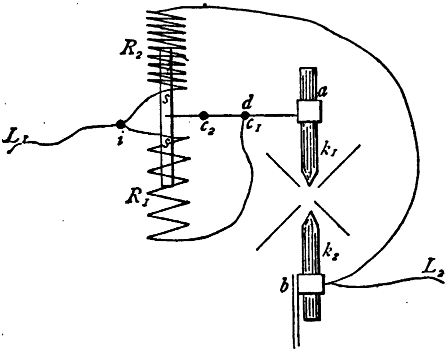

FIG. 22.—DIAGRAM OF DIFFERENTIAL LAMP.

The action is as follows, supposing the current entering at L_1, found the two carbons far apart from one another; in this case it can only traverse coil R_2, since the other branch containing coil R_1 is interrupted by the separation of the carbons. Coil R_2 will therefore suck in rod S, and will thereby lower arm c_1 of lever c_1c_2 and the upper carbon will descend, until it touches the lower carbon point. At this moment the thick wire coil R_1 will absorb nearly the whole of the current, and will draw down rod S. The lever arm c_1 is hereby raised, and as soon as this happens the former coupling between it and the carbon-holder A is restored, the carbons withdraw from each other, and the arc is lit.

The arc resistance, which evidently increases with the length of the arc, is now added to that of circuit R_1; more current will therefore again pass through coil R_2, until, for a definite resistance of the arc, the attractions exercised upon rod S by the coils R_1 and R_2 are equal. The carbons are now slowly consumed, while an equal length of the arc is always preserved by a gradual ascent of the lever-arm c_2, and descent of the arm c_1. As soon as the lever arm has reached its lowest possible position, it again releases the upper carbon-holder, and the carbon begins slowly to descend, but only very little, since by the shortening of the arc, the lever arm c_1 is raised again, and its coupling with the upper carbon-holder restored. And now the rod S and lever arm c_1 only slightly deviate from their respective highest and lowest position, and the upper carbon k_1 slides down sufficiently to compensate for the combustion of the carbon. At the same time, the lower carbon being fixed, the locality of the arc is gradually lowered. If, from some cause or other, the current varies, this will have no effect on the steadiness of the lamp, because the currents in both branches increase or decrease by an *equal* multiple of their former strength, and therefore the sum of their attractions on rod S will remain zero, and the equilibrium will not be disturbed. The resistance of the arc is dependent on the relative effect of R_1 and R_2 on Rod S, and this latter is determined by the number of windings of the coils, or by the greater and lesser depth to which the rod penetrates into one of the coils. For this purpose the upper coil can be raised or lowered by means of a screw. A number of these lamps can be placed in one circuit, since the resistance of the arc of each lamp, quite independently from any other lamp in the circuit, adjusts itself at a certain given value. Every arc thereby receives the same length and a definite illuminating power, and the problem of division of the arc light is practically solved. Further, if the carbons of any one lamp in the circuit are consumed, the circuit would nevertheless remain closed through the fine wire coil of the respective lamp, but, in consequence of the high resistance of the coil, would be weakened to such an extent that the light of the remaining lamps would suffer. To prevent this occurrence, each lamp is provided with

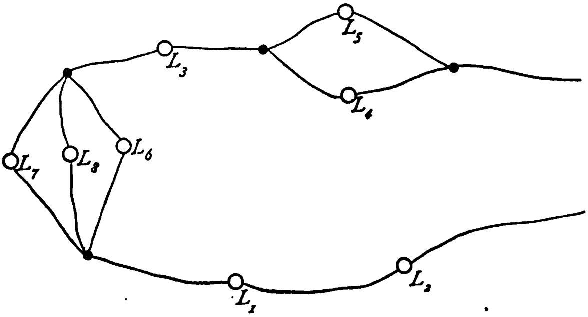

Fig. 23.

a contact which short circuits it immediately on its extinction.

Both alternating and continuous current dynamos can be used for such installations, and the lamps can be arranged in parallel, in series, or in compound parallel, and lights of very different intensities can be produced in this way. So, for instance, the connection shown in Fig. 23 gives lamps of three different intensities.

Lamps L_1, L_2, L_3 give the strongest light; lamps L_4 and L_5 are less intense; whilst lamps L_6, L_7, L_8 have the least illuminating power.

The number of differential lamps which can be placed in one circuit is very large, and only limited—1. by the necessary E. M. F. of the generator; 2. by the risk of fire and life attending the use of machines of high E. M. F.

The multiplication of arc lamps has now become quite common. Brush, Weston and Thomson-Houston in America, and Crompton, Piette and Krizik, &c., in Europe, have carried the system very far.

Central Stations for Arc Lighting.

From various reasons, such as a most iniquitous Act of Parliament, the comparatively low price of gas, over-speculation, and various others, no central stations are to be found in this country, whilst quite a number of them have been established in the United States, and lately also in Germany, Italy, Austria, etc. That these stations are working successfully has been confirmed by Mr. Preece, in his excellent paper read before the Society of Arts on Dec. 5, 1884. These stations are mostly built on the same principle, and only differ by the number of lamps, light machines, and steam engines, and by the construction of the regulating apparatus. They all have a main switch board to connect machines and leads, according to special requirements, but, as a rule, do not employ reserve machines. The whole working naturally is infinitely more simple than in the case of incandescence installations, because the time during which the arc light is required, as well as the number of lamps in one circuit, is always limited, and therefore the particular circuit which has to be connected to the machine during certain specified hours must always be well known at the station. The dynamos of all the companies working the stations have current regulators which automatically regulate and keep constant the current at the central station, so that any individual lamp can be switched on or off according to the requirements of the case. The lamps, supports, leads, etc, are supplied to the subscriber by the company, and remain the latter's property. It is generally admitted that central stations begin to pay when the number of lamps supplied exceeds one hundred. The price paid for the light supplied is everywhere a matter of agreement, no measuring apparatus for current expended in arc lamps being in use at the present moment, and therefore varies between rather wide limits, according to the number of working hours of the lamps. The usual price for private subscribers is about £30 per lamp per year, the working hours being from 5 to 10 o'clock P.M. in winter, and from 7 to 10 o'clock P.M. in summer, Sundays excepted. On Saturdays light is supplied for an additional 1 to 2 hours. For lamps which are kept burning the whole day 4*s*. are generally charged per lamp per day, but certain reductions are made according to the number of lamps used. The Brush Company in Boston, for instance, charges

For 25 lamps, per day, per lamp, 2*s.* 8*d.*
„ 6 „ „ „ „ „ 3*s.*
„ 1 lamp „ „ „ „ 4*s.*

The consumer is not charged for laying of leads or cables. Considerable reduction of price is made to municipal authorities; they generally pay from 2*s.* 6*d.* to 3*s.* per lamp per night; control is exercised by night-watchmen, and payment regulated accordingly. That these installations satisfy all reasonable demands is proved by the fact, that in all the streets of the towns which have adopted electric light, the gas lamps have been removed, the lamp posts only remaining. The lamps themselves are fixed on the tops of perfectly plain, unsightly iron-posts, and the overhead wires are fixed to high wooden poles, which in some instances carry from 10 to 12 horizontal arms with 10 wires each. These posts and poles are, as Mr. Preece complains, a perfect eyesore; the latter are quite rough and not even painted, and are made the more hideous from the way in which repairs are effected. The workmen in this case do not use ladders for climbing up the poles, but climbing irons attached to their boots, which of course shortens their work, but does not add to the beauty of the poles.

The wires used by the Brush and Thomson-Houston Companies have a diameter of 5 mm. whilst the United States Co. (Weston) uses wire of 6 mm., the lamps of the latter company requiring much stronger currents.

The Brush and Thomson-Houston Companies' lamps take a current of 9·5 to 10 ampères, with an E. M. F. of 50 volts and 1·6 to 3·2 mm. distance of carbon points, whilst the Weston system employs lamps taking about 16 ampères, 25 volts, and having only 0·8 to 1 mm. distance of carbon points. The arc light obtained in all these cases is of 2,000 candles nominal. The number of lamps in one circuit generally does not exceed 40, and this number already requires a very considerable E. M. F. (40 × 50 = 2,000). In this respect the Weston system presents a great advantage over the others, and justly claims credit for the fact, that no loss of life has ever occurred from the currents employed by them.

The total length of the individual circuits is in some cases very considerable. Brush, for instance, has several circuits of 12 miles feeding 36 arc lamps, with a so-called 40-lighter. Weston, in New York, has also a circuit of 12 miles, feeding 14 lamps with 3–10 lighters, and reckons that for each mile the loss in the leads corresponds to the consumption of one lamp. The longest circuits of the American Electric and Illuminating Co. (Thomson-Houston) measure 8 miles.

The Brush Current Regulator.[*]

In installations in which it is desired frequently to vary the lights burning in one circuit, and it is inconvenient to alter the speed of the machine, an automatic regulator is used. By this apparatus the amount of current generated by the machine is automatically controlled to suit the number of lamps in action at any one time. The apparatus is of very simple and effective character, and depends for its principle on the fact, that the electrical resistance of a series of plates or laminæ of carbon varies with the degree of pressure to which they are subjected. Four sets of carbon plates are connected with two terminal screws on the generator, so connected up that the regulating apparatus forms a shunt circuit across the electro-magnets. From this it is evident that if a high resistance be placed in the shunt, the greater portion of the current generated in the machine will be transmitted through the coils of the electro-magnets, and the strength of the magnetic field will be proportionately increased; while, on the other hand, if the shunt be of low resistance, a greater portion of the current will be diverted by it from the field circuit, and the strength of the magnetic field will be reduced. The columns of carbon plates constitute the variable resistance, the pressure upon them being controlled by a lever actuated by a pair of solenoids included in the main circuit of the machine. Thus, if any of the lamps in that circuit be extinguished, a larger amount of current passing through the solenoids causes two iron cores to be drawn into them; the lever is thereby lifted, and the carbon plates are pressed closer together, thus reducing the resistance of the shunt and causing a greater amount of current to be diverted from the magnet coils. The magnetic field being thereby reduced, the machine absorbs less motive power, and when the lamps are turned on again the operation is reversed, and thus the power required to drive the generator is proportioned to the work it is required to do. This apparatus will automatically control a Brush 40-lighter, so that the number of lamps in one circuit may be varied from 40 down to 2 without altering the speed of the generator.

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[*] James Dredge, 'Electric Illumination,' p. 427.

Weston's Current Regulator.

This apparatus consists mainly of a number of brass strips arranged in a circle, over which moves a sliding contact connected as well as the first of the brass strips to the field magnet windings of the dynamo. As the sliding contact moves over the brass strips, different resistances are introduced into the field circuit, and the magnetic field is thereby strengthened or reduced. The movement of the sliding contact is automatically regulated by the action of an electro-magnet coil traversed by the main current.

The Thomson-Houston Current Regulator.

For the regulation of the Thomson-Houston dynamo, a hollow stout wire coil is placed in the main current of the machine and is provided with an iron core which is, according to the current action, more or less deeply sucked into the coil. The core is attached to one end of a lever whose other end acts on the brushes of the dynamo, and places them in such position as to vary the E. M. F. and therefore to maintain the current at the requisite strength. This apparatus also adjusts variations of E. M. F. which may arise from irregularities in the motion of the driving engine. It is claimed by the Thomson-Houston people that their lamps show a steady light even on varying the revolutions of the armature between 900 and 1300 per minute, an occurrence which is by no means rare in factories where other machines beside the dynamo are driven by the engine.

Glow Lamp Installations.

An important advance in the connection of lamps with the light machine has lately been made at the *New York central station of the Edison Company.*[*] This station feeds at the present time 13,000 lamps of 16 candles each, and has 870 subscribers. The remaining Edison central stations in the United States, supply altogether about 20,000 lamps. The cost per lamp hour is 1·125 cents (2½ farthings). The leads at the outset were too thick and expensive, and by diminishing the cross section of the wires the waste of power between dynamo and lamps would have become excessive. This latter objection has been removed by increasing the resistance of the carbon filament, so that at the present moment a 16-candle lamp only takes ·7 ampère and a 10-candle lamp ·5 ampère.

The most important advance however was made when two machines were connected in series and their joint electromotive force used, whilst by the employment of a third wire branching off from the connection of the two dynamos, the E. M. F. of but one dynamo is made available for any given room. The diagrams of Figs. 24 and 25 show the two systems. In Fig. 24 we see the usual connection of two parallel wires with dynamo A, the lamps in the main as well as in the branch circuits being arranged in parallel. The current coming from the dynamo passes through the positive main circuit and all branch circuits connected with it, and after performing its work returns to the negative terminal of the dynamo. In this system the greatest difference of potential naturally is between the two brushes, reaching in the central station a maximum of 115 to 130 volts, taking into account a certain waste arising from the resistance of leads and lamps. The Edison system of central stations, where the loss arising from the division of light amounts to about 10–20 per cent. generally employs lamps of 105 to 110 volts, corresponding to lamps of 90 to 100 volts, used for single installations where the fall of potential does not as a rule exceed 5 per cent. It will easily be understood that for central stations employing a large number of lamps, where the external resistance of the circuit is diminished in comparison with the internal resistance of the dynamo, it is desirable that the individual lamps should have the highest possible resistance, so as to preserve a proportionately high total external resistance. In order to afford a clear insight into this highly important point, let us assume the dynamo of Fig. 24 to feed 450 16-candle lamps, the circuits at *a*, *b*, *c* and *d* representing a group of 50 lamps each.

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[*] *Electrotechnische Zeitschrift*, 1884, No. XII., p. 49.

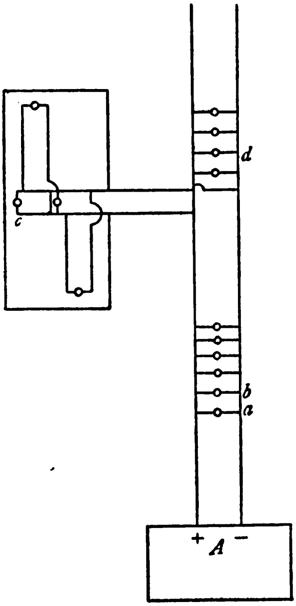

FIG. 24.

Before turning on any of the lamps we find an infinitely higher resistance in the leads which we suppose to be perfectly insulated, and, on neglecting the resistance of the magnetic field, about ·01 ohm in the dynamo. If we now turn on a lamp of 150 ohms resistance, and neglect the resistance of the leads, we have in the dynamo $\frac{1}{15000}$ of the total resistance of the whole circuit. At this stage of the experiment the resistance of the lamp circuit is maximum. If we now turn on 450 lamps, their joint resistance is ·33 ohm.

If after having reached the normal efficiency of the dynamo we wish to increase the number of lamps, a second machine connected in quantity with the former, must be used in order to obtain a sufficiently low resistance of the joint armatures, and the highest possible E. M. F. for the supply of the lamps.

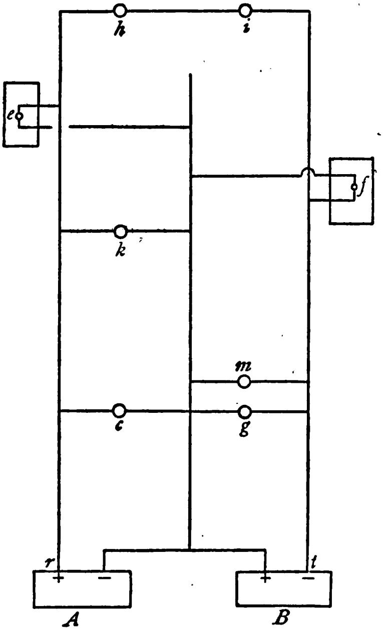

Fig. 25

Let us now connect in series dynamo A with dynamo B of the same type, (Fig. 25) both driven by the same engine, and at some point of the connection between the two dynamos let us attach a third wire; then we have the positive pole of the combined system at *r* and the negative pole at *t*, whilst the intermediate wire is positive as regards B and negative as to A. If the two machines run at normal speed the difference of potential between *r* and *t* will be 220 volts, and if we now introduce a lamp at *c* dynamo A will perform the requisite work, and the current return to the negative pole. In the same way, if a lamp is inserted at *g*, dynamo B alone will supply the current. If C and G burn simultaneously the effect will be the same as if *h* and *i*, or *k* and *m*, were in use, because the double E. M. F. will work through the same resistance and produce the same number of ampères as before, the intermediate, or as it may be more fitly called, the neutral or compensating wire taking no part in the action. If the number of lamps on one side exceeds that on the other, the current will flow through the neutral wire from or to that one machine which performs most work, and the deflection of the needle of an ammeter will indicate this difference. We can therefore light up any building or any room, *e* or *f*, by placing lamps on either side of A or B. Let us suppose these points to be half a mile distant from the dynamo, then we get for this length a current of double the E. M. F. compared with Fig. 24. In order to obtain the same efficiency we have a wire of only half the cross section compared with Fig. 24, and our two wires will only have one quarter of the weight of that of the former installation. The addition of a third compensating wire increases the expense only by three-eighths of the original outlay.

To make this point clearer still, let us consider the joint resistance of *a* and *b*, Fig. 24, $\frac{150}{2} = 75$ ohms. With an E. M. F. of 110 volts, *a* and *b* absorb $\frac{110}{75} = 1{\cdot}46$ ampère. On removing the lamps to *c* and *g*, Fig. 25, they have a joint resistance of 300 ohms, being connected in series, and therefore absorb $\frac{220}{300} = {\cdot}73$ ampère. And this half of the original current having double the E. M. F. can be sent from the dynamo to the lamps through double the resistance, that is through half the mass of copper. The same intensity of light therefore is obtained with one-fourth the weight of copper. The expended energy remains in both cases the same, for whether we take 110 × 1·46 or 220 × ·73 we get the same result, viz. 160·6 Watts = $\frac{1}{5}$ horse power. A great saving is thus effected, not only in the weight of the expensive copper conductors, but also in the iron pipes, in the requisite insulating material, in the weight of the junction boxes connecting the individual sections, in the cost of laying the cables and of repair.

The Berlin Central Station of the Edison Company.[*]

The three-wire system described above is also in use at this station, affording a saving of copper of 50 per cent., and allowing at the same time to turn on or off any single lamp in the circuit.

The main cables branch off from the main switch board to the measuring apparatus of the respective houses, and from them to the lamps. The measuring apparatus has been described on p. 69; a number of consumers kept an accurate account of the hours during which the lamps were burning, and the account agreed in the most satisfactory way with the results obtained by the Company's measurements, and which were used as basis for the charge made by the Company.

Amongst the apparatus placed in the machine room with a view of ensuring an absolute security of working, we have first of all to mention the so-called *Earth-connection* Indicator, which is connected with the two main cables, and enables the engineer in charge at any time to form a clear idea of the insulation of the entire network of conductors. Although the whole of the leads are most carefully insulated, are mostly fastened to porcelain studs, and, if necessary, protected by wooden boxes against any external damage, yet carelessness or intention may bring about an earth connection or short circuiting. Even in this latter case no dangerous heating of the conductors would ensue, because every branch circuit and every place where a conductor of smaller cross section branches off, is provided with a double safety cut-out, which melts, and breaks the current before a heating of the wires can take place. Yet in order to avoid losses of current, these earth leaks ought immediately to be detected and as speedily be removed. The apparatus used for this purpose consists of two lamps in series placed in the main circuit, and whose connecting wire is in contact with earth. These two lamps, which receive only half the E. M. F. will, under ordinary conditions, only be brought to dull red heat, but as soon as in the neighbourhood of the earth contact of one of them a leak to earth of a few ohms resistance occurs, the second lamp will burn up brightly and warn the engineer that a considerable earth connection exists in the circuit. But it is of importance to detect not only these more serious disturbances, but to receive warning as long as the resistance still amounts to 1000 or 2000 ohms. For this purpose an alarm-bell is interpolated in the connection of the lamps to earth, and this bell begins to ring for a current of ·1 ampère and an E. M. F. of 100 volts between the two main cables ($\frac{100}{\cdot 10} = 1000$ ohms). Several other shunt-resistances may be arranged parallel to the alarm-bell; so, for instance, on inserting a shunt resistance which has the same resistance as the alarm-bell, half the current will pass through the latter and the other half through the shunt resistance; the ringing of the bell will require a current of double strength, or ·2 ampère. The resistance of the insulation would in this case (neglecting the resistance of the lamps and of the alarm-bell), have sunk to about 500 ohms. In this way it is therefore possible to indicate by signals whether the resistance of the insulation is 1000, 500, 200, &c., ohms. It is however necessary that the engineer, after having been made acquainted with the existence of a short circuit, should also be able to ascertain its locality without much trouble. To find this out in the ordinary way, would in the case, for instance, of 100 houses being supplied by the central station, be a very difficult and wearisome task. The whole of the houses would have to be disconnected from the main leads, one after another, and likewise the conductors in the house where the short circuit has shown itself, disconnected from each other in order gradually to localise the exact spot where the damage has occurred. In order to simplify this task, at least in the case of serious short circuits, a leaden cut-out is placed at the central station which is on the one hand connected to earth and on the other hand by means of the switchboard both with the positive and negative main cable. If an earth connection occurs and the leaden plug is connected with the positive conductor the current will cause a direct short circuit, and another leaden plug placed at the consumer's house, and of smaller size than the one at the central station will melt, and the lamps connected with that particular conductor will be extinguished. The consumer will naturally ask for a new plug, and thus the Company will be informed where the insulation has been damaged.

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[*] *Electrotechnische Zeitschrift*, 1885, No. VIII., p. 325.

Besides this earth connection apparatus, there is at the central station an E. M. F. indicator which, through an optical and acoustic signal, announces too high or too low a difference of potential. The pointer of a Siemens and Halske Voltmeter is provided with a contact lever which closes the current, brings a red or green lamp to incandescence and rings a bell, when the current does not possess its normal E. M. F. This simple contrivance has the advantage, that it can easily be fixed to any measuring instrument and adjusted by the engineer himself for any desired E. M. F. The voltmeter is connected to a switch board, and, by means of it, to the terminals of each single machine as well as to the main connecting points of the main leads. Mistakes are hereby avoided which, with the use of several instruments become almost unavoidable. There are also in the machine shed a number of resistances, four for each machine, which can be inserted or cut out, as soon as a considerable number of lamps are lit or extinguished, but especially when the driving motors vary in speed, or in case that the machines, in consequence of a difference in their working hours, should be heated to a different degree. The different resistances can be joined together for common action.

We now come to the contrivances used for cutting out or introducing the machines into the circuit. The engineer must first of all know how much current is supplied by the central station in order to ascertain whether the machines are working at full power or not; and for this purpose, the current from the machines passes through an ammeter before arriving at the main switch board. The ammeters generally in use are only constructed for comparatively feeble currents, and to use shunts for these ammeters has not been found advantageous in the measurement of feeble currents as they occur during day-time; the current, therefore, before passing into the main cable, influences a magnetic needle movable round its axis, whilst a weight which can be displaced, and a fixed magnet, endeavour to bring back the magnetic needle to its original position. An ammeter of this kind enables us to measure strong as well as feeble currents with the necessary accuracy. It is not calibrated in the laboratory, but, in order to take into account external influences in the machine shed, at the place itself where it is to be used. The calibration is, for the sake of simplicity, made in 16-candle lamps and not in ampères, by introducing at constant E. M. F. 10, 20, 100, 500, 1000, etc., lamps and marking on the scale the place at which the pointer stands for the respective number of lamps. By displacing the magnet and weight, this empirical division is kept fairly proportional. It is a special advantage of this apparatus that it can easily be calibrated and controlled by the engineer employed. If this lamp-counter indicates that the machines are working at full power, he has to introduce a new machine into the circuit. Were he to do this in the usual way, by exciting the electro-magnets from the main circuit, running the machine at the same speed as the others and suddenly introducing it, the steam engines hitherto at work would now suddenly actuate an additional motor, they would commence running at a higher speed, and the lamps would burn more brightly until the engine regulator entered into the function. Variations of this kind, be they ever so slight, must be carefully avoided in perfect installations, and with this view the arrangement shown in Fig. 26 has been adopted. Let us suppose machines I. and II. to be running, feeding together 600 lamps, and that a third machine had to be introduced. The engineer has first of all, by means of a switch D, to connect the machine to the so-called lamp battery L in the machine shed, and to place 400 lamps (the

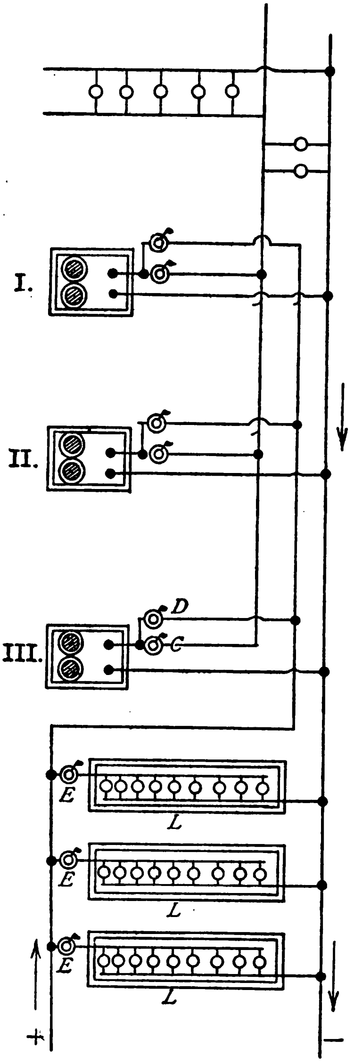

Fig. 26.

same amount of work as that performed by either of the two other machines) in this battery; he then regulates the machine by the adjustable resistances until it shows exactly the same E. M. F. as the other machines, and then only he closes the cut-out at C, so that now machine III. is connected on the one hand to the lamp battery, and on the other to the main lead. The three machines together now feed 1200 lamps, 400 lamps each; the original performance of machines I. and II. is not altered in the least, and the engine has no cause for running any faster. The machines being coupled together the engineer slowly cuts out the lamps burning in the lamp battery and inserts resistances in case the machines should increase their speed through the cutting out of the lamps. After the whole of the lamps of the lamp battery have been short-circuited, the cut-out D is opened again. In this manner a perfectly steady working can be ensured.

Besides the ampèremeter which, as mentioned above, is placed in the main circuit, to show to the engineer whether a machine has to be connected up or switched off, there is a similar apparatus placed in all branch conductors leading from the individual dynamos to the main circuit. These are intended to indicate whether the active dynamos are working up their efficiency. Such a continuous control of current strength in each dynamo is absolutely necessary, because even the slightest variations of electro-motive force—and these variations are unavoidable — are sufficient to modify to a considerable extent the efficiency of the machine, as will be seen from the following considerations:

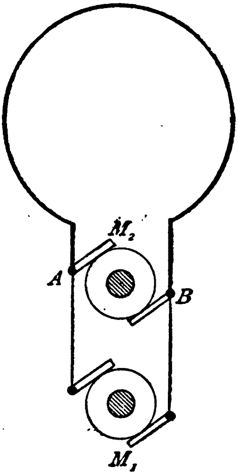

FIG. 27.

Let E_1 be the E. M. F. of the machine M_1 (Fig. 27); r_1 the resistance of the armature of this machine inclusive of the conductor leading to the main circuit AB; c_1 the current of machine M_1 in the armature and conductors (the dynamo being supposed to be shunt wound and excited by the main current); r^2 & c_2 being the corresponding values of machine M_2; C the current, E the E. M. F. and R the resistance of the main circuit.

We then have, according to Kirchhoff's law:

$$c_1 r_1 + C R = E_1$$
$$c_2 r_2 + C R = E_2$$
$$c_1 + c_2 = C, \text{ and from this—}$$

$$c_1 = \frac{E_1\left(1 + \frac{r_2}{R}\right) - E_2}{r_1 + r_2 + \frac{r_1 r_2}{R}}$$

$$c_2 = \frac{E_2\left(1 + \frac{r_1}{R}\right) - E_1}{r_1 + r_2 + \frac{r_1 r_2}{R}}$$

Let us now suppose machine M_2 to supply n times the current of machine M_1, and we get

$$c_1 = n\,c_2$$

or $E_1\left(1 + \frac{r_2}{R}\right) - E_2 = n\,E_2\left(1 + \frac{r_1}{R}\right) - n\,E_1$; and hence,

$$E_1 = E_2 \frac{1 + n + \frac{n r_1}{R}}{1 + n + \frac{r_2}{R}}$$

Putting $n = o$ in this equation, we get

$$E_1 = E_2 \frac{1}{1 + \frac{r_2}{R}}$$

that is to say, dynamo M_1 would give no current at all if the E. M. F. produced by it were

$$E_1 = E_2 \frac{1}{1 + \frac{r_2}{R}}$$

Putting in the above equation $n = \cdot 5$, machine M_1 would only yield half the current of machine M_2 if

$$E_1 = E_2 \frac{1 \cdot 5 + \frac{r_1}{2R}}{1 \cdot 5 + \frac{r_2}{R}}$$

If we put for n a negative simple fraction, we get a value of E_1 which shows that machine M_1 is driven by machine M_2 acting as a motor. A simple example will clearly explain the above formulæ; let us suppose that two Edison machines are to be arranged in parallel for 100 16-candle lamps each, and that they are jointly to feed 125 lamps of 150 ohms each.

In this case we get the following values:

$$R = 1 \cdot 2 \text{ ohm}$$
$$r_1 = \cdot 05 \text{ ,,}$$
$$r_2 = \cdot 05 \text{ ,,}$$

If M_2 is running at 100 volts, M_1 according to the above formulæ would give no current if its E. M. F. were

$$E_1 = 100 \frac{1}{1 + \frac{\cdot 05}{1 \cdot 2}} = 96 \text{ volts.}$$

If the two machines feed 180 lamps, through an external resistance of ·84 ohm, dynamo M would only do half the work of dynamo M_2 if

$$E_1 = 100 \frac{1 \cdot 5 + \frac{\cdot 05}{1 \cdot 68}}{1 \cdot 5 + \frac{\cdot 05}{\cdot 84}} \text{ or}$$

$$E = 98 \text{ volts.}$$

Let us now assume that the two machines are only to feed 60 lamps, through an external resistance of 2·5 ohms, that they are to be driven by the same transmission and arranged in parallel; in this case, dynamo **M_2** running at 100 volts would supply the entire current for the 60 lamps, and, in addition to it, an equal amount of work for dynamo M_1 acting as an electromotor, if this latter only gave an E. M. F.

$$E_1 = 100 \frac{\cdot 5 - \frac{\cdot 05}{5}}{\cdot 5 + \frac{\cdot 05}{2 \cdot 5}} = 94 \text{ volts.}$$

In all these examples dynamo **M_2** would be overrun, and in the latter case a considerable loss of work would equally ensue, although dynamo M_1, acting the part of an electromotor, would assist in driving the common transmission.

The slightest variations of E. M. F. thus are sufficient to produce in dynamos, which are arranged in parallel, most abnormal efficiencies; and such variations may easily arise from the slightest change in the number of revolutions, the unavoidable inequalities of construction, the slipping of driving belts, an uneven position of the brushes, or through a slight heating of the dynamo. All these considerations will sufficiently explain the difficulties which have been hitherto encountered in a parallel arrangement of dynamos, and will account for the failure connected with the opening of the New York Edison Central Station.

The different ampèremeters at the Berlin Central Station provide against similar contingencies; as soon as the engineer is warned that a certain dynamo gives more or less current than the others, he either places in circuit, or cuts out from the circuit, a regulating resistance, until all the machines show the same efficiency.

Fifteen Siemens differential arc lamps were also fed from the central station, in three circuits of five lamps each: the lamps were connected in series, and all the leads were connected to a common switch board, so that each machine communicated with either of the three circuits. This arrangement presented the serious drawback, that the consumers had always to burn the whole of the lamps, or at least had to pay for the feeding current, because a compensating artificial resistance had to be placed in circuit for every extinguished lamp. It was also found most inconvenient that all the lamps had to be burned with the same luminous intensity, whilst the arc lamps in the open air ought to have given more light than those burning under cover; and a further difficulty arose from the fact, that in some cases an additional arc lamp was required, or that it would have been advantageous to replace an arc lamp by a number of glow lamps—requirements which could not be fulfilled by a series connection of lamps.

This serious defect has been remedied by replacing the Siemens lamps by a new arc lamp which lends itself to a parallel arrangement. Two of these lamps in series are placed in parallel in the circuit of the glow-lamps and no power is wasted now by the interpolation of useless resistances, nor need the cost of leads be unnecessarily raised by diminishing the electromotive force.

Current distribution by Secondary Generators.

This method was first shown on a large scale at the Turin Exhibition of 1884 by *Gaulard and Gibbs*, and consists in passing the current of an alternating dynamo into an induction apparatus, and thereby, with a very slight loss, obtaining a current of the same electrical energy, but possessing a different strength, which can be made to vary according to the requirements of the case. The induction apparatus consists of a primary and secondary coil wound round the same iron core. The alternating current passing through the primary coil produces, by induction, in the secondary coil a similar current. In most cases where secondary generators are used, in practice the object of their employment is to convert a comparatively feeble current of high E. M. F. (such as is supplied by the alternating dynamo) into a strong current of lower electro-motive force, and this object is attained by making the primary coil of one single piece, and dividing the secondary coil into several equal parts, which can, by means of a commutator, be joined into one single or a multiple circuit. The opposite construction is chosen if it is intended to increase, not the strength, but the E. M. F. of the current. The coils of the generators shown at the Turin Exhibition consisted of a number of superposed thin copper discs, of the form shown in Fig. 28.

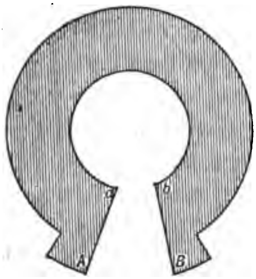

Fig. 28.—Disc of Secondary Generator Coil.

The protruding part A of one disc is soldered to B of a second, and B to A of the following disc, and so forth. A coil is thus formed, of which each disc represents one winding. The primary and secondary coils are of similar construction, but the solderings are effected in an inverse sense. Insulation is obtained by placing between the consecutive discs pieces of thin cardboard, coated with gum, of the same shape as the copper disc. The coil thus formed is mounted on a vertical ebonite tube, into which is inserted a cylindrical core of iron wire. Two small metallic columns and two square wooden boards form the support of the apparatus. On the upper board are fixed the terminals of the two coils and a commutator, by means of which the apparatus can be switched into the primary circuit, or cut out from it. The commutator can join into one single or into a multiple circuit, into which the secondary coil can be formed, connection being made by the insertion of one or more metal plugs. To regulate the action of the generator the iron core is raised or lowered in the ebonite tube, and fixed at any height by means of a lateral screw.

Zipernowsky, Déri, & Blathy's Transformer.

Another, and, according to Prof. Ferrari's account,* a better form of secondary generator, has been constructed by Messrs. Zipernowsky, Déri & Blathy, and is manufactured by Messrs. Ganz & Co., of Budapest.

The inventors started from the idea that, in order to increase the yield of an induction apparatus, its inductive action must be increased as much as possible, and that the most appropriate means of obtaining this end is in increasing as much as possible the action of the magnetized iron in the apparatus.

On considering all the possible causes of the loss of energy which operate during the conversion of electric currents, we find that the transformer which has the greatest yielding capacity will also offer the greatest advantages with regard to the useful effect, especially if the apparatus is constructed in such a manner as to prevent any dispersion of the lines of magnetic force, and as to place all the turns of the coil through which the currents flow, as it were, in a homogeneous and magnetic atmosphere. The action of the induction will, in that case, be the same on each particle of the copper wire, and the chief cause of the loss of energy, the Foucault currents, will be prevented.

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* 'Memorie della R. Accademia delle Scienze di Torino,' 2nd series, Vol. XXXVII., p. 1, and *La Lumière Electrique*, t. XVI., p. 399.

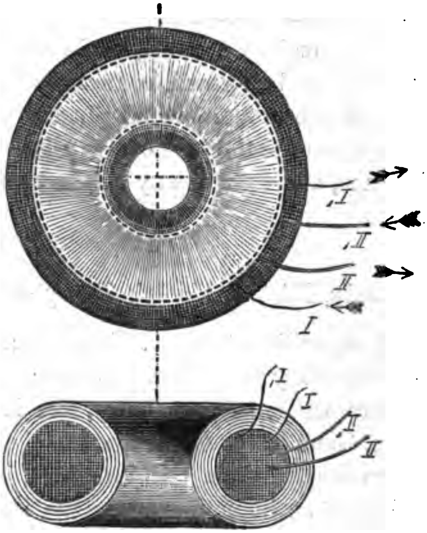

FIG. 29.

The principal forms of the apparatus are shown in Figs. 29, 30, 31, 32, 33, 34. The fundamental form is the ring which is wound round in such a manner that no poles can be formed in it. The ring shown in Fig. 29 consists, like the

Gramme, of a bundle of iron wires, which is surrounded by the primary and secondary coils. In the case of the ring represented in Figs. 29 and 31, iron and copper have changed places. Fig. 30 is the perspective view of the new apparatus, and Fig. 31 shows it in section and plan. The core consists of insulated copper wires, which form two or more spirals, these are formed into a ring with circular or any other section, as required. They are then wound round with an insulating covering, and finally wound closely round with thin insulated iron wires. The electric current in the copper wires, as well as the lines of

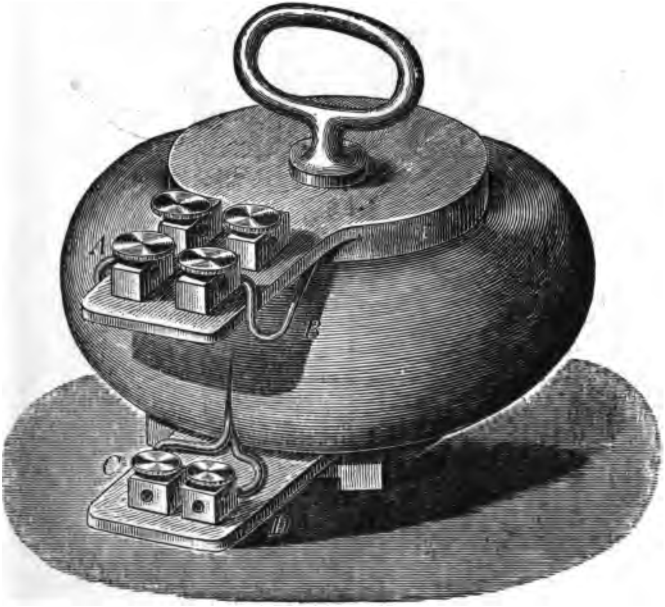

FIG. 30.

magnetic force in the iron wire, circulate in such a manner that both circuits form planes perpendicular to each other. The iron wires form to a certain extent a protecting covering for the copper wires, whose ends pass through a gap in that covering. The iron wires are either covered with cotton or coated with varnish.

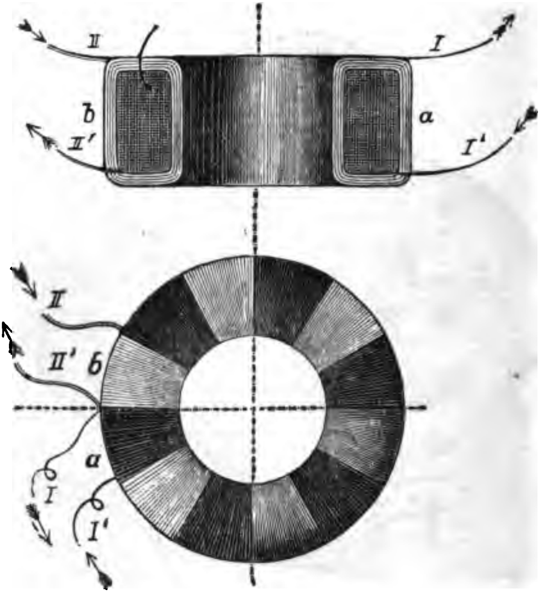

FIG. 31.

A prominent feature of the apparatus is that there is nothing in it which can give rise to Foucault's currents, and the development of heat in its metallic part is, indeed, extremely small. In consequence of the arrangement of the active iron, a comparatively small quantity of current is required to magnetize the masses of iron. From 1 to 2 per cent. of the electrical energy is generally sufficient for that, whilst the consumption of energy by the spirals amounts to only ½ to 1 per cent. of the total yield.

Different modifications of this transformer are represented in Figs. 32, 33, 34. In all these forms the same fundamental principle obtains; that is to say, that the copper conductors are completely surrounded by iron, and that the latter is so arranged that the lines of force form circles in planes which are perpendicular to the copper conductors; whilst currents which might be set up in a direction parallel to the copper conductors can have no access to the iron. The columns in Figs. 32 and 33, as well as the box-shaped apparatus in Fig. 34, consists of sheets of iron, which are insulated from one another either by a coating of varnish or by sheets of paper; they are piled up in such a way that the protruding insulated copper wires are perpendicular to their surfaces.

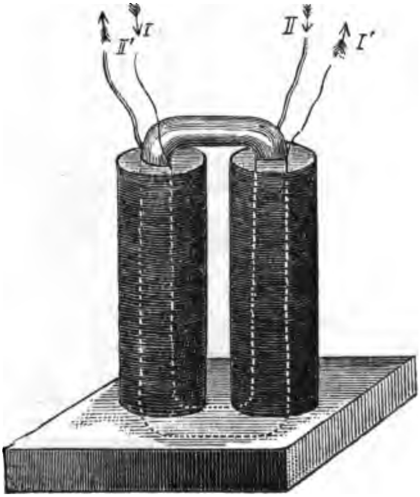

Fig. 32.

Let us now consider the action of the current reversals in the transformer, and study the connection between the different phenomena, also in the case of variable activity of the apparatus, having especial regard to the circumstance, that the resistance of the wire spirals is extremely small and, even with the greatest allowable current strength, scarcely exceeds $\frac{1}{100}$th of the external resistance.

Let E_1 be the difference of potential between the terminals of the transformer when the primary current c_1 enters; e_1 the opposing E. M. F. of the primary spirals; E_2 the difference of potential between the terminals of the

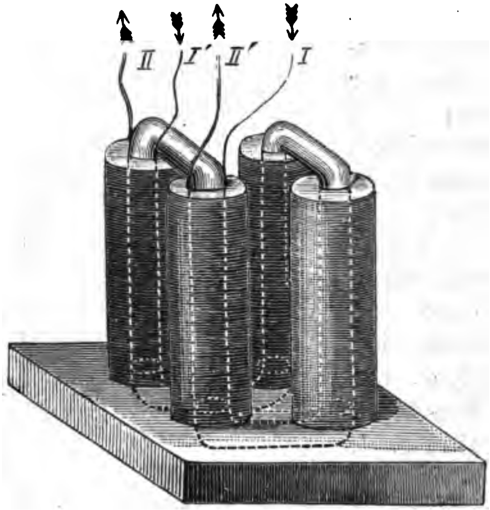

Fig. 33.

secondary current, c_2; e_2 the E. M. F. of the secondary spiral during induction; R the resistance of the external secondary circuit (resistance of the lamps, etc.), and r_1 and r_2 the actual resistance of both spirals respectively. There is in both circuits

$$E_1 - e_1 - r_1 c_1 = 0 \text{ and } e_2 - (R + r_2)\, c_2 = 0.$$

But as the values of r_1 and r_2 are in all cases extremely small, the products $r_1 c_1$ and $r_2 c_2$ may be neglected, and we have then the equations

$$E_1 = e_1 \text{ and } e_2 = R\, e_2$$

which are for good apparatus sufficiently correct.

As further, in the case of the present transformers, the inductive action is—in consequence of the above-mentioned properties—exactly the same in all spiral windings, if we represent the E. M. F. of a single turn by E, and the number of the primary and that of the secondary turns by n_1 and n_2 respectively, we shall have

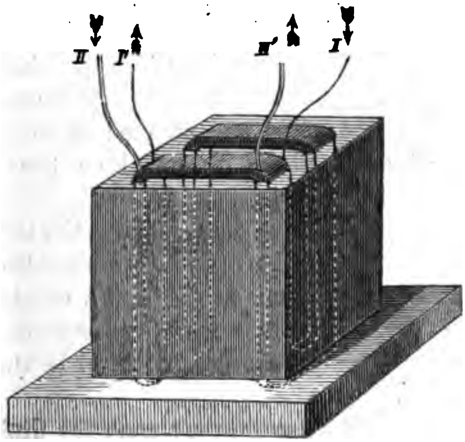

FIG. 84.

$$e_1 = n_1 E \text{ and } e_2 = n_2 E,$$

therefore

$$e_1 = \frac{n_1}{n_2} e_2$$

and this, combined with the above equations, gives

$$E_1 = \frac{n_1}{n_2} R\, c_2$$

where $\frac{n_1}{n_2}$ is a constant factor which depends on the construction of the apparatus, and may also be called the *co-efficient of conversion* of the transformer.

From the last equations we derive the following deductions:

1. The difference of potential between the primary terminals is always proportional to the difference of potential between the secondary terminals; or,

2. The ratio between the E. M. F. at the primary and the secondary terminals is constant, and equal to the so-called co-efficient of conversion of the transformer.

The system of current distribution proposed by the inventors of this apparatus, and adopted at Budapest and a number of other places, is based on the following considerations:

1. The safest lighting system requires the lamps to be placed in parallel, and the installation must therefore be arranged in such a manner as to show a constant mean difference of potential between the two conductors starting from the secondary generator, whatever be the number of lamps alight.

This is effected by keeping constant the difference of potential at the terminals of the primary circuit of the transformer. We have seen in fact that, in this case, the difference of potential between the terminals of the secondary circuit will also remain constant, as long as the external resistance is high in proportion to the internal one, and this will always be the case in practice.

2. Arrangements must be made for switching on and off new transformers without interfering with the work of the others, and this is effected by placing the transformers in shunts of the main leads starting from the central

stations, and having a constant difference of potential; it is evident that in this case the current supplied by the dynamo must increase with the number of transformers, as in the case of a light installation by means of a compound dynamo; only the regulation of an alternating dynamo is more complicated than that of a continuous current machine.

When the resistance of the circuit decreases by the introduction of new transformers, the current increases, and this brings about a lowering of E. M. F. at the terminals of the machine, a larger amount of energy being absorbed by the internal resistances; in order, therefore, to have a constant difference of potential between the main leads, to which the transformers are connected, the E. M. F. of the machine must be increased by a regulating apparatus. The inventors obtain this effect by using a small transformer, placed in the main circuit, which acts as an additional exciter on the electro-magnets. The Ganz machine (self-exciting, alternating) used is intended to give 50 to 60,000 Watts; in this machine the field-magnets are movable and the armature coils are fixed; a small portion of the induced current is redressed by a special commutator, and used for exciting the electro-magnets. To the brushes of this commutator are connected the extremities of the secondary circuit of the small transformer or *compensator*, and thereby the exciting current is strengthened in proportion to the strengthening of the total current of the machine. A constant difference of potential is thus, to all intents and purposes, obtained at the terminals of the machine.

Messrs. Ganz & Co. made a large installation of this kind at the Budapest Exhibition, 1885. They fed 1060 glow lamps from their central station. Copper conductors of 4·5 mm. diameter conveyed the alternating currents from the dynamo to the transformers, some of which were at a distance of as many as 1300 metres from the central station. Installations have also since been made in Rome, Lucerne, etc.

It is most interesting to note that this system promises a new field for the alternating machine, which by some over zealous electricians had already been consigned to the lumber room.

Arc Lamps coupled parallel with Glow Lamps.[*]

In many cases, especially in mills and factories, it is necessary to employ both arc and glow lamps. If the installation is not sufficiently large to justify the employment of two separate dynamos, one for the arc lights, the other for the glow lamps, it is very desirable to find a method whereby both kinds of lamps can be fed from the same circuit independently of one another. It is also sometimes necessary to employ arc lamps of different power in the different parts of the same installation, a condition which can evidently not be fulfilled by the usual arrangement of putting lamps in series. One method of accomplishing this is by placing all the lamps in parallel connection, but in this case a comparatively large resistance must be inserted in each branch circuit, entailing a heavy loss of electrical energy. The reason for this will be obvious, if we consider what would happen if arc and glow lamps were coupled parallel without any resistance in the arc circuits. Let us assume that the E. M. F. required for an arc lamp is about 43 volts and that the dynamo is perfectly self-regulating and able to maintain this E. M. F. at its terminals, no matter how the total current may vary. If now, through impurities in the carbons, the resistance in one of the arcs were to increase slightly, the current through that arc will slightly diminish. If the lamp does not regulate immediately—that is, if the length of arc remains unaltered for ever so short a time—this would still further increase the resistance, and the arc would be broken. As soon as the arc is broken, the carbons run together, and for an instant the main leads are thereby short circuited. This lowers the E. M. F. in the other lamps, which in their turn lose their current and go out. Whilst the first lamp recovers, the carbons of one of the other lamps come into contact, thus extinguishing again all the rest. Under these circumstances it is impossible to obtain a steady light. To overcome this difficulty, let us fix the E. M. F. at 65 volts, and insert with each arc circuit sufficient resistance to bring the E. M. F. at the lamps down to 43 volts. To avoid this comparatively heavy loss of 22 volts, two arc lamps are placed in series, and each series in parallel with the others and with the glow lamps. This arrangement has, in the first place, the advantage of reducing the influence the disturbance in one lamp may have on the whole system. It also lessens the disturbances in each lamp, since the other lamp coupled in series with it acts to a certain extent as a steadying resistance. To make this system successful it is necessary that the regulating mechanism in each lamp should be exceedingly delicate, and that it should act quickly yet gradually.

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[*] *Electrician*, Aug. 28, 1885, p. 296.

Mr. Schuckert of Nuremberg recommends for this purpose the Pilsen lamp, which, when so coupled, only requires 43 volts to give a steady light. The additional resistance required in each branch is therefore exceedingly small, and a loss of only 10 volts out of a 100 is incurred.

We may add that results nearly as satisfactory as these are commonly obtained in England with a number of differential lamps. The pressure between the mains is generally fixed at 110 volts, and each arc lamp is regulated so as to require from 45 to 47 volts. The pressure utilized in the lamps is therefore about 92 out of 110 volts generated.

Cost of Electric Lighting.

On summing up the various and conflicting opinions on this important question, we arrive at the one indisputable fact, that a well-arranged arc installation is considerably cheaper than gas light, and also preferable to the latter on account of its higher illuminating power.

During the early period of electric lighting, the dates and figures concerning the cost were chiefly supplied by the contracting firms which undertook the installation and also the working for a sum to be paid annually. There can be no doubt that the figures thus supplied were in most instances too low, and that the respective firms rather lost than gained by these transactions. An entirely different *modus operandi* has obtained of late; electric light installations are now made at the expense of the consumer and worked by him, and we can now quote a series of authentic figures, furnished by the consumer, and clearly showing the superiority of arc light over gas light as far as the expense is concerned. The case is different with regard to glow light, which is in all cases dearer than gas, especially where only a small number of lights are required. For domestic lighting the glow lamp will remain an article of luxury until a cheaper mode of generating electricity has been found. In localities, however, such as theatres, clubs, hotels, factories, etc., where a large number of gas flames can be replaced by fewer incandescent lamps, the expense will be found not much to exceed that of gas.

It has been shown in § 4 that the most expensive method for generating electricity is by means of a primary battery. This mode should therefore only be resorted to where want of room or other individual peculiarities of locality forbid the use of a driving engine. The cheapest and most rational mode of generating electricity is by means of the dynamo, and here again the cheapness depends upon the choice of the engine. The dearest motor decidedly is the gas engine, and it should be chosen only in cases where a steam engine cannot be employed for certain local reasons, such as want of room, risk of fire, objectionable noise, etc. One great advantage, however, of the gas engine is that it can be set in motion at a moment's notice, and this renders it eminently fitted for installations which have only to act periodically.

We now proceed to give some authentic figures which will allow us to form an accurate opinion on the question of expense.*

1. Lighting of a shed 5 metres (17 feet) high, and 8000 square metres area, by 32 Pilsen lamps of 1200 candles each, fed by 4 Schückert dynamos. Inclusive of night work 3000 working hours are counted; the motive power was supplied by a 300 H.-P. steam engine, 30 to 32 of the total horse-power being absorbed by the dynamos. The cost of H.-P. per hour was about $\frac{1}{4}$*d.*

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* W. H. Uhland, 'Das Electrische Licht,' Leipzig, 1884, p. 434.

	£
Cost of electric installation complete . . .	980
Cost of transmissions and driving belts . . .	105
Share of boiler and engine	600
	£1,685

	£
Interest of capital and depreciation at 10% . .	168
Consumption of carbon points (6 centimetres per hour per lamp; price of 1 metre = 1*s.* 3*d.*) = 3000 × 32 × 6 ÷	288
Cost of steam power 3000 × 32 × 4½*d.* = . .	100
Working expense of 32 lamps for 3000 hours . .	£556
Expense of 1 lamp for 1 hour	1½*d.*

The number of gas flames required for lighting this shed was 524, with a consumption of 120 litres per hour, therefore

524 × 120 × 3000 = 188,640,000 litres = 188,640 cubic metres.

Taking the price of gas inclusive of depreciation as low as 1*d.* per cubic metre (2*s.* 3*d.* per 1000 cubic feet) we get a yearly expense of £786, or a saving of £230 per annum = 30% in the case of electric lighting.

On comparing the relative illuminating power of the two modes of electric illumination, we find—

32 lamps of 1200 candles each . .	38,400 candles.
Deducting 40% for dispersion of light by dulled globes	13,360 „
Leaves.	25,040 candles.
524 gas flames of 12 candles each . .	6,288 candles.

We therefore get 4 times the amount of light at two-thirds of the expense of gas. We have further to take into account advantages which cannot be expressed in figures, such as the fact, that as much work both with regard to quantity and quality can be performed at night as by day, that the risk of fire is reduced to a minimum, that colour and material can be distinguished and tested as by sunlight, and finally that no deleterious generation of heat or vitiation of the atmosphere takes place. All these considerations must bring us to the conclusion that, in all cases where illumination with arc lamps is feasible, no other mode of lighting can be designated as rational.

It will be of interest to calculate what the cost of an incandescent installation for the same place and purpose would amount to. Supposing the 524 gas flames had to be replaced by as many Edison B lamps, fed by 4 large Schuckert dynamos, we find—

	£
Cost of electric installation complete	1000
Cost of transmissions and driving belts	125
Share of boiler and steam engine for 40 H.-P.	750
	£1875

	£
Interest and depreciation 10% excl. lamps.	172
Consumption of lamps for 3000 hours (with life of 1000 hours at 6s. per lamp) 524 × 3 × 6 =	472
Cost of steam power 3000 × 40 × ¼*d*.	125
	£769

Or almost the same price as gas.

Most instructive are the following data supplied by Engineer L. Bach of Hanover, in the 'Wochenbericht des Vereins deutscher Ingenieure,' for lighting a weaving mill at Linden near Hanover. In the first instance is given the cost of plant for a steam engine of 20 to 25 indicated H.-P., which is designed to drive a dynamo for feeding 150 glow lamps of 16 to 20 candle each.

	£
1. Building site about 100 square metres at 10*s*.	50
2. Boiler house	45
3. Chimney	90
4. Shed for steam engine and dynamo	90
5. Foundations of machines	25
6. Boiler	100
7. Foundations and brickwork for boiler	75
8. Boiler fittings	49
9. Two separate feeds for boiler, injector, pipes, and mounting	11
10. Steam and water pipes, safety valves, stopcocks, mounting	33
11. High pressure engine of 20 to 25 H.-P., high-speed and without condenser	250
12. Driving belts	35
13. Lighting installation of boiler and engine shed	3
14. Personal supervision of building and mounting	5
15. For emergencies	15
	£876

Under certain circumstances a steam engine may be available powerful enough to drive the dynamo in addition to any other work it may have to perform, then the items up to No. 12 must be omitted from the calculation, and the working expenses of a steam installation of 20 to 25 H.-P. are—

	£
5% interest of capital invested	44
2% depreciation of items 2–5	5
5% ,, ,, 6–13	26
For repairs, items 2–5, 1%	3
,, ,, , 6–13, 1½%	8
Cleaning boiler	3
Lubricating, cleaning and tools	4
Wages, one man 150 days at 3*s*.	23
For 150 days	£116

or for one day of 4 working hours, 15*s*. 6*d*.

On account of interrupted working, the boiler fire has to be lit afresh both morning and evening, involving a consumption of about 4 cwt. of coal at 13*s*. per ton (this is the average price of Westphalian coal) = 2*s*. 7*d*. For the high speed engine we may calculate a consumption of 30 lbs. of steam for each hour and horse-power, therefore a consumption for one horse-power hour of 4 lbs. of coal, and for 4 hours 20×4×4=320 lbs. of coal costing 2*s.* 2*d.* Twenty horse-power for 4 hours cost therefore

	s.	*d.*
	15	6
	2	7
	2	2
£1	0	3

and for one hour 5*s.* Twenty indicated horse-power give about 18 effective H.-P., and these are sufficient for driving a dynamo feeding 150 glow lamps of 16 to 20 candles each. The motive power for these lamps therefore cost 5*s.* per hour, or $\frac{2}{5}$*d.* for one lamp hour. The prime cost of an incandescent installation of 150 lamps amounts to about £500, the life of the lamps may be taken from 400 to 800 hours; lamps of 10, 15, 20 and 25 candles cost from 4*s.* to 6*s.* At an average life of 600 hours the lamps would have to be replaced once, for which 3*s.* are charged per lamp. From this we find the cost of one glow lamp per hour:

	£
5% interest on £500	25
10% depreciation and working expenses . . .	50
150 lamps at 3*s.*	23
150 lamps for 150 days of 4 hours	£98

1 lamp per day of 1 hour = $\frac{1}{4}$*d.*

The whole working expenses for 1 hour are therefore $\frac{2}{5}+\frac{1}{4}=\frac{13}{20}$*d.* or not quite three farthings per lamp per hour.

Taking the price of gas at 2*s.* 6*d.* per 1000 cubic feet, we find that *electric light is twice as dear as gas.*

The *Centralblatt der Bahnverwaltung*, 1882, No. 45, p. 408, gives the following data on the illumination of the Strassburg railway station, upon the authority of the Imperial Director of State Railways.

For Entrance Hall:

6 Siemens' differential lamps (350 candles) in one circuit, replacing 54 gas flames.

For lighting the line:

2 Siemens' differential lamps (1200 candles) in one circuit, replacing 34 gas flames.

For platforms, vestibule, goods sheds:

12 Siemens' differential lamps (150 candles) driven by 2 Siemens' alternating dynamos.

For refreshment-rooms, luggage-room, offices, etc.:

45 Edison glow lamps of 16 candles each and 36 lamps of 8 candles (life of 800 hours guaranteed, driven by 2 Edison machines).

As common motor for 3 dynamos an old locomotive engine of 24 horse-power is used.

Prime cost:

	£
Arc light	1,287
Glow light	561

Working expenses (inclusive interest and depreciation of capital invested).

			Per lamp hour.	Per candle.
Differential lamp of	1200	candles	7·56*d.*	·006 penny.
" "	350	"	3·7*d.*	·011 "
" "	150	"	2·21*d.*	·015 "
Glow lamp of	16	"	·30*d.*	·018 "
"	8	"	·14*d.*	·019 "
Gas flame of	12	"	·26*d.*	·022 "

(4·32 cb. feet of gas per hour per flame at 4*s.* 4*d.* per 1000 cb. feet.)

This price of course is nearly twice that of gas in this country, and therefore the cost of a gas flame of 12 candles is reduced to ·014 penny per candle, or about the same as that of an arc lamp of 150 candles, and considerably lower than that of a glow lamp of 16 candle power.

The *Electrotechnische Zeitschrift*, December, 1882, p. 449, gives the results of electric lighting of the "Leipziger Strasse" in Berlin, carried out by Messrs. Siemens and Halske, and as compared with the lighting with gas of the adjoining Friedrichs Strasse. The experiment was carried out throughout the whole year, and from it we find that the cost per hour for lighting an area of about 1500 square metres was—

With 3 Siemens' Regenerative gas burners of 120 candles each	·32 shilling.
With 3 Lacarrière's Ring burners of 105 candles each	·48 "
With Bray's 3 flame burner of 105 candles each	·48 "
With electric light of 2½ times intensity of 880 candles	·38 "

It can no longer be doubted that electric lighting, quite apart from any other consideration, presents an economical advantage in all cases where a number of arc lights are supplied in one circuit by a continuous current, as well as where steam power is already available for driving the dynamo, and need not be expressly fitted up for the purpose, also "cela va sans dire" where a natural motive power exists.

If however it is a question of replacing a number of gas flames by an incandescent installation, the price of gas must decide the financial point. It will then be found that where, as in this country, the price of gas is from 2*s.* to 3*s.* per 1000 cubic feet, incandescent light will cost about twice as much as gas; but, on the other hand, we get an illumination vastly superior in every respect to our present system.

Before leaving the subject of installations, we have to say a few words on the necessary precautions to be taken so as to ensure the safety, both as regards life and fire, of an electric light installation.

A committee was appointed on May 11, 1882, by the Society of Telegraph Engineers and Electricians, to consider this subject, and drew up the following report:—

These rules and regulations are drawn up for the reduction to a minimum, in the case of electric lighting, of those risks of fire which are inherent in every system of artificial illumination, and also for the guidance and instruction of those who have, or who contemplate having, electric apparatus installed in their premises.

The difficulties that beset the electrical engineer are chiefly internal and invisible, and they can only be effectually guarded against by "testing" or probing with electric currents. They depend chiefly on leakage, undue resistance in the conductor, and bad joints, which lead to waste of energy and the dangerous production of heat. These defects can only be detected by measuring, by means of special apparatus, the currents that are either ordinarily, or for the purpose of testing, passed through the circuit. Should wires become perceptibly warmed by the ordinary current, it is an indication that they are too small for the work they have to do, and that they should be replaced by larger wires. Bare or exposed wires should always be within visual inspection, and as far out of reach as possible, since the accidental falling on to, or the thoughtless placing of other conducting bodies upon such conductors would lead to "short circuiting" and the consequent sudden generation of heat, due to an increased current in conductors not adapted to carry it with safety.

The necessity cannot be too strongly urged for guarding against the presence of moisture and the use of "earth" as part of the circuit. Moisture leads to loss of current and to the destruction of the conductor by electrolytic corrosion, and the injudicious use of earth as a part of the circuit tends to magnify every other source of difficulty and danger.

The chief dangers of every new application of electricity arise from ignorance and inexperience on the part of those who supply and fit up the requisite plant.

The greatest element of safety is therefore the employment of skilled and experienced electricians to supervise the work.

I. *The Dynamo machine.*

1. The dynamo should be fixed in a dry place.
2. It should not be exposed to dust or flyings.
3. It should be kept perfectly clean, and its bearings well oiled.
4. The insulation of its coils and conductors should be practically perfect.
5. All conductors in the dynamo-room should be firmly supported, well insulated, conveniently arranged for inspection, and marked or numbered.

II. *The Wires.*

6. Every switch or commutator used for turning the current on or off should be constructed, so that when it is moved and left, it cannot permit of a permanent arc or of heating.
7. Every part of the circuit should be so determined, that the gauge of wire to be used is properly proportioned to the currents it will have to carry, and all junctions with a smaller conductor should be fitted with a suitable safety

fuse or protector, so that no portion of the conductor should ever be allowed to attain a temperature exceeding 150° F.

8. Under ordinary circumstances complete metallic circuits should be used; the employment of gas or water-pipes as conductors for the purpose of completing the circuit should not in any case be allowed.

9. Bare wires passing over the tops of houses should never be less than seven feet clear of any part of the roof, and all wires crossing thoroughfares should invariably be high enough to allow fire escapes to pass under them.

10. It is most essential that joints should be electrically and mechanically perfect and united by solder.

11. The position of wires when underground should be clearly indicated, and they should be laid down so as to be easily inspected and repaired.

12., All wires used for indoor purposes should be efficiently insulated, either by being covered throughout with some insulating material, or, if bare, by resting on insulated supports.

13. When these wires pass through roofs, floors, walls, or partitions, or where they cross or are liable to touch metallic masses, like iron girders or pipes, they should be thoroughly protected by suitable additional covering, and where they are liable to abrasion from any cause, or to the depredations of rats or mice, they should be efficiently encased in some hard material.

14. Where indoor wires are put out of sight, as beneath flooring, they should be thoroughly protected from mechanical injury, and their position should be indicated.

N.B.—The value of frequently testing the apparatus and circuits cannot be too strongly urged. The escape of electricity cannot be detected by the sense of smell, as can gas, but it can be detected by apparatus far more delicate. Leakage not only means waste, but in the presence of moisture it means destruction of the conductor and its insulating covering, by electric action.

III. *Lamps.*

15. **Arc lamps** should always be guarded by proper **lanterns**, to prevent danger from falling incandescent pieces of carbon and from ascending sparks. Their globes should be protected with wire netting.

16. The lanterns, and all parts which are to be handled, should be insulated from the circuit.

IV. *Danger to Person.*

17. Where bare wire out of doors rests on insulating supports, it should be coated with insulating material, such as indiarubber tape or tube, for at least two feet on each side of the support.

18. To secure persons from danger inside buildings, it is essential so to arrange and protect the conductors and fittings, that no one can be exposed to the shocks of alternating currents of a mean electromotive force exceeding 100 volts, or to continuous currents of 200 volts.

19. If the difference of potential within any house exceeds 200 volts (a higher E. M. F. has been forbidden by the Board of Trade since this report was issued), the house should be provided with a "switch" so arranged that the supply of electricity can be at once cut off.

PART II.

ARC LAMPS.

It has been observed that, by the passage of an electric current through a moderate conductor, part of the electricity is converted into heat, and the temperature of the conductor rises accordingly. This rise of temperature is proportional to the resistance, and under certain conditions is so considerable that it renders the conductor incandescent. If we interpolate two carbon rods in the circuit, connecting one of the carbons to the positive, the other to the negative pole of a source of electricity, and allow these two carbons to touch each other, we produce what is called the *Voltaic arc.* Through the incomplete contact of the two carbons, and the small cross section which the electric current finds for its passage at the points of contact, the resistance opposed to it becomes so great that the temperature of the carbon points immediately rises to incandescence. If now the two rods are withdrawn from one another, but only a short distance, the current is not interrupted, but there is formed between the points, as it were, a bridge of incandescent carbon particles, carried chiefly from the positive to the negative electrode. In consequence of the increased resistance which the current now encounters in its passage through the air, the generation of heat becomes very considerable indeed, the carbon particles as well as the ends of the carbons are raised to white heat, and radiate forth a dazzling light—the arc light. The name of Voltaic arc has been given it in honour of the great physicist with whose battery it was first obtained.

The intensity of the light obtained depends on the strength of the current and the character of the carbon electrodes. For every distinct relation between these two factors there exists a definite distance of the two carbons at which the arc shows its greatest intensity. On increasing the distance of the two carbons, the intensity rapidly diminishes, and the arc is extinguished altogether as soon as the distance between the two carbons has been lengthened to such an extent that the current can no longer traverse the intervening layer of air.

On throwing an enlarged projection of the arc on a white screen, we soon find that the most intense light emanates not from the arc between the two carbons but from the incandescent carbons themselves, and also that the positive carbon soon loses its point and assumes a hollow crater-like shape, and further, that highly incandescent particles fly from this latter to the negative carbon. The globules, which may be observed in molten condition on the surface of the carbons, are drops of fused silica, which is very rarely absent even from purified carbon, and interferes with the steadiness and intensity of the light. As soon as these globules reach the extreme and hottest ends of the carbons, they cause a perceptible hissing noise and a sudden diminution of light.

For arc lighting continuous current machines are almost exclusively used, and by these currents the upper or positive carbon is consumed nearly twice as quickly as the lower negative one. On using alternating currents, where the polarity of the carbons changes at every instant, and the current at one moment flows from the upper to the lower, and immediately afterwards from the lower to the upper carbon, the waste of the two carbons is uniform, the positive carbon does not assume the crater-like shape, both retain their pointed form. This pointed form would evidently be most advantageous for obtaining the largest possible light-angle in the vertical plane, since it permits a free spreading of the light both in an upward and downward as well as in a horizontal direction. In most instances, however, we require light not so much for the ceiling as for the floor; we have, in fact, to make special arrangements for reflecting the light downwards, and the crater-like shape of the upper carbon is therefore a decided advantage in itself; it acts like a reflector, and prevents the light rays from assuming an upward direction. This will explain the preference given to the continuous current machine for arc lighting; in fact, 65 per cent. of the total light-rays obtained are radiated downwards, less light is dispersed on walls and ceilings, and the illumination of the floor thereby rendered more effective. It has besides been ascertained by numerous experiments that the waste of carbons is considerably less for continuous than for alternating currents.

In many cases, as, for instance, for lighthouse illumination, a considerable advantage is gained by throwing the light rays as much as possible in a given direction (towards the sea), and this effect is obtained partly by optical contrivances, such as mirrors, lenses and prisms, partly by arranging the carbons in such a way that the axis of the lower carbon, as nearly as possible, coincides with the front edge of the upper one. Experiments made by Douglas show that the effect of such a one-sided arc is 50 per cent. superior to that of the common arc.

Now, although the consumption of carbon for the maintenance of the arc is but slow, yet the waste, especially that of the positive carbon, is sufficiently large to cause an interruption of the current, unless by some proper contrivance the carbons are fed forward so as to preserve a constant distance corresponding to the highest intensity of light. In the early days of arc lighting this feeding had to be done by hand; Foucault was the first to use the electric current itself as a regulating agent, by conducting it, before its passage through the carbons, into an electro-magnet coil provided with a soft iron core. This core is magnetised by the passing current, and attracts an armature which is connected with the carbons. If, by the combustion of the carbons, the arc is extended beyond its normal length, the resistance opposed by the air to the passage of the current increases, the current is proportionately diminished, the effect of the electro-magnet is weakened and the armature is released. The connection of the armature with the carbons is made in such a way that the movement of the former causes a simultaneous approach of both carbons; the positive carbon, moving through double the distance of the negative one. By this simultaneous movement of the carbons the arc in the first instance preserves its normal length, and, secondly, also its position in space, this latter consideration being of great importance in many practical cases.

As soon as the carbons are drawn into too close a proximity, so that the resistance to be overcome by the current is lessened more than is necessary for the maintenance of the arc, the strength of the current traversing the electro-magnet increases, the armature is attracted anew, and a corresponding withdrawal of the carbons ensues. From this results a position of equilibrium of the armature, corresponding to the normal length of the arc, and the regulation of this latter by a displacement of the armature.

Since the construction of the first self-regulating arc lamp an enormous number of these lamps have been constructed on the principle of electrical self-regulation, but of all these comparatively few are in practical use now. Amongst those that have survived, and which we may consider the fittest, we may mention the following: the Brush, the Weston, the Thomson-Houston, the Siemens differential, the Pilsen, the Gülcher, the Bürgin, the Ganz (Zipernowsky), the Crompton, the Gramme, and amongst monophotal lamps, the Jaspar and Serrin-Lontin. We do not mean to imply that these are the only good lamps constructed, but simply that they are the lamps most extensively used in practice, and on that account most deserving of our attention. Before proceeding to the description of individual lamps, we must summarise, in as few words as possible, the conditions to be fulfilled by an efficient arc lamp. They are:—

1. That the carbon points must touch at the first passage of current, and must again come into direct contact as soon as the light is extinguished.

2. That by the action of the current the carbons withdraw from one another.

3. That the distance of the two carbons should remain constant by automatic regulation, and should be such as to maintain the arc under the most favourable conditions of efficiency and economy.

4. That it is desirable in most cases that the arc should maintain its position in space.

5. That the carbons should last as long as possible.

6. That the mechanical contrivances, viz., details of

construction of lamps, should be as simple as possible, and not require frequent repairs and alterations.

7. That the lamps, after having been provided with fresh carbons, should require no further personal attention of any kind.

As regards the requirements of special parts of the lamps and their connections, we refer the reader to the following paragraph, and only once more call attention to the important advance made in the construction of arc lamps by placing the regulating apparatus in a shunt of the main current, as has already been mentioned on p. 91, This improvement, the same in principle everywhere, has not been carried out to the same degree of perfection in different lamps, and hence the difference in efficiency of different lamps. The all important point in the regulation of a lamp is the maintenance of the carbon points at a certain constant distance, so as to preserve a constant resistance of the arc. Experience shows that with a distance of 3 mm.* between the carbon points a good steady light is obtained. But even an arc of this length has already a resistance of several ohms, and it is, therefore, evident that even the most insignificant variations of distance of the carbons must considerably affect the low total resistance of the circuit, especially if we take into account the fact, that the continuous waste of the carbons, constituting, as they do, the worst conducting part of the circuit,† must necessarily cause a continuous decrease of resistance, and also that the connection of the wire with the carbon is not in the immediate neighbourhood of the area of combustion.

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* If the arc is lengthened, the pure white light emanating from the incandescent carbons may appear coloured by the influence of the light produced in the arc itself; this would not only interfere with the distinction of colours, but would also produce other disturbing effects.

† Carbon is 3000 times a worse conductor than copper. The fact that contrary to the property of solid conductors, the resistance of carbon decreases with the rise of temperature (according to Siemens ·000345 for each degree between 0° and 140° C.), is not of much account, considering the small area of the burning surface.

To obtain a lasting regulation of the length of arc during working hours we are thus confined to very narrow limits; and our regulating apparatus must therefore be of the most perfect kind. We may safely say that even in the best arc lamps the performance is yet very far behind the requirements, and if such is the case even in lamps of good workmanship, what will be the result with lamps of inferior make?

Under otherwise equal conditions, in a special case, the illuminative power rose from 547 to 1140 candles per H.-P. for an increase of distance of the carbons from 1 to 5 mm.; at the most convenient distance of 3 mm. a steady light of 874 candles was obtained. If the arc becomes too long, the light is extinguished, the distance, however, at which extinction ensues varies considerably. The arc in this respect behaves in a peculiar manner; the shorter it is the lower is, generally speaking, its resistance, and also that of the circuit, and therefore, according to Ohm's law, the stronger the current; increase of length of the arc consequently weakens the current. And yet, notwithstanding this weakening of current, the longer arc shows the higher illuminating power; the explanation will simply be found in the fact mentioned in § 4, that an increase of resistance produces a rise of temperature. Unfortunately the relations between heat and light are not sufficiently known to allow of an accurate determination of the length of arc; this determination must be left to experience. We are taught that an arc which is extinguished at a length of between 4 and 5 mm. gives the best light, the illuminating power naturally depending on the current strength. The arc, however, when near its limits of extinction is most sensitive to even the slightest outside influences, and 2 to 3 mm. have therefore been adopted in practice as the most convenient length of arc. The most crying evils may thus be remedied, yet there remain quite a number of other defects which seriously interfere with the steadiness of arc light. Amongst these we mention that the generation of heat in the arc will always be more or less irregular, because the rise of temperature does not correspond to the quantity of heat. This is owing to the fact, that the conductors consisting of comparatively stout carbon rods do not radiate heat uniformly. We have further to consider that the rise of temperature of the conductor is inversely proportional to its specific heat; and also, that the resistance of the arc constantly varies, owing to solid particles being carried off from the electrodes; as well as to the unavoidable differences in the distance of the carbons, the formation of ashes and slake and the different constitution of the surrounding atmosphere; and further, that the flames themselves excite electric (flame) currents, etc. etc.

§ 1. PREPARATION OF CARBONS FOR ARC LAMPS.

One of the most essential conditions for the production of a steady arc light is the employment of good carbons, and a few words on this important point will not be considered out of place. Sir Humphry Davy, who first observed the Voltaic arc, used sticks of wood charcoal extinguished in water or mercury, but the combustion was extremely rapid, and this sort of carbon would never have supported the electric light for any length of time. A great progress was made when Foucault conceived the idea of using carbon deposited in gas retorts, by cutting it into square sticks. This carbon however lacks homogeneity and contains silica and alkaline earths, which fuse, vaporise, and shiver the carbon, to the detriment of the steadiness of the flame.

In 1842 Bunsen tried to obtain hollow cylinders of moulded carbon for his nitric acid batteries; for this purpose he cast a mixture of dry pulverised tar and glue into moulds and baked them. He thus obtained a porous carbon cylinder of little compactness. To remedy this latter defect, he dipped the cylinder into treacle and baked it a second time; the sugar stopped up the pores and left a very pure and compact carbon behind. The operation was repeated as long as there were any holes left, and till a faultless cylinder was obtained.

A number of different methods for manufacturing artificial carbons have been proposed since. The composition and mode of preparation are very different, and partly kept secret by the respective firms. In Germany it is chiefly the firm of Siemens Brothers of Charlottenburg which supplies the market, not only in Germany but also abroad. Their mode of preparing the original carbon sticks is not known, but the subsequent operations are the following: The carbon stick is hollowed out along its entire length and firmly closed at one end; a solution of certain materials containing a fine powder of the same nature as the carbon stick in suspension is then introduced by means of a force pump, or in some other way, under high pressure. This solution displaces the gases which otherwise are very difficult to expel out of the carbon; the hole is thus gradually filled with powdered carbon, and finally a massive and very compact carbon is obtained.

In 1857 Lacassagne and Thiers dipped pieces of gas carbon into a solution of caustic potash or soda, and then exposed them to a very high temperature to transform the silica of the carbon into soluble silicate. By washing the carbon sticks afterwards with hot water, and exposing them to a current of chlorine at red heat, compounds which had not been acted on by the potash were transformed into volatile chlorides of silicon, potassium, iron, etc. The light obtained with these carbons is a little steadier, but they produce a great deal of ashes and slake.

The carbons manufactured by Carré and Gaudoin belong to the best articles of this kind. They consist of 15 parts of very finely pulverized pure coke, 5 parts of calcined lamp-black and 7 to 8 parts of syrup (30 parts of cane sugar to 10 parts of gum). The mixture is carefully pulverized, made into a paste with water, put into a press and forced through a die of the form to be given to the pencils, and baked several times at a very high temperature. After the first baking it is immersed into a concentrated syrup of sugar or burned sugar and left for some time in the boiling liquid, with two or three intervals of cooling to facilitate the penetration of the syrup into the pores. The carbons are finally washed in boiling water to clean their surfaces. After having been dried, the carbons are subjected to a second, third, or more processes similar to that just described, until the required density is obtained. The final drying is effected very slowly in stoves, at a temperature of about 170°, and lasts about 15 hours. One of the chief advantages of the Carré carbons, which deservedly enjoy a high reputation, is their extreme toughness; they can be used in pieces of ½ metre length without fear of breaking.

Gaudoin's carbons share in no inconsiderable degree the excellent qualities of the Carré carbons. They consist almost exclusively of very pure carbon, and are made by destructive distillation, in closed graphite crucibles, of tar, bitumen, pitch, oil and other organic substances which leave behind nearly pure carbon. The residue of distillation is reduced to the finest possible powder and made into a sort of paste, from which, under very high pressure in a hydraulic press, cylindrical sticks are formed. Experiments made by Fontaine show that the consumption of a pair of such carbons of 11·25 mm. thickness was 8 centimetres per hour.

Napoli of Paris has also been successful in producing carbons of high quality and on a large scale. The materials he employs are gas tar and the residue of coal slowly distilled at red heat. The coke, which is first reduced to an impalpable powder, is afterwards carefully screened and then mixed with the tar in the proportion of 75 of coke to 25 of tar. When the mixing is completed, the compound is very compact, and requires considerable pressure to force it into its ultimate form. This is effected by a specially constructed hydraulic press, and by forcing the carbons coming from the press through a draw plate. In baking the carbons, Napoli in the first stage carefully avoids a higher temperature than that at which the component parts are obtained, he only raises them to dull red heat. After the first baking and cooling, the carbons are subjected to a second and similar operation, only this time they are raised to a white heat, which drives out the final traces of gas and leaves the carbons of great hardness and with a fine fracture like that of crucible steel. In this condition and without any further treatment, the pencils can be used for lighting purposes; they burn with perfect steadiness, and give a pure white light. It is claimed, moreover, that the relative consumption as compared with the

Carré carbons of similar size, and in the same time, is as 1 to 3·3.

Besides the artificial carbons described above, sticks of Siberian graphite are also used. This material, according to Jaquelain,* obtains, on being purified, double the illuminating power which it possesses in a natural state, and this illuminating power is $\frac{1}{6}$ higher than that of artificial carbon. The three methods for purification proposed by Jaquelain are the following:—

1. The carbons raised to bright red heat are exposed to a current of chlorine gas.

2. The carbons are exposed to the action of caustic soda or fused potash.

3. The carbons are exposed at ordinary temperature to the action of hydrofluoric acid.

These three methods yield carbons which, although not quite free from hydrogen, do not contain any mineral impurities. For powdered carbon the use of chlorine is quite sufficient. It has been employed with the best effect for preparing carbon which has been used by Dumas for determining the equivalent weight of carbon. Under the combined influence of chlorine and of a high temperature, silica, alumina, magnesia, the alkalies and metallic oxides are transformed into volatile chlorides, and the hydrogen present in the carbon changes into hydrochloric acid, which escapes with the other chlorides. A few kilogrammes of retort carbon are for this purpose cut into prismatic sticks, and then, at bright red heat, for at least 30 hours, exposed to the action of a current of dry chlorine; the carbon is thereby rendered extremely porous. These pores must as much as possible be filled up again, in order to restore the original density, conductivity, and inferior combustibility of the retort carbon. This is effected by passing carburetted hydrogen over it equally at bright red heat and for about 5 to 6 hours. The process only succeeds when carried out at a very high temperature and very slowly, so that the deposited carbon particles can properly penetrate into the pores. If these conditions are not fulfilled, a layer of solid carbon is deposited on the sticks, and these latter finally bake together.

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* Uhland, 'Das electrische Licht,' Leipzig, 1884, p. 228.

The purification with soda is effected much more rapidly. The carbon is placed in a cast-iron vessel, and treated with caustic soda containing three equivalents of water, whereby the silica and alumina are transformed into alkaline silicates and aluminates (alumina acting the part of an acid). By washing with warm distilled water, these two, as well as the soda in excess, are removed, and by further treatment with warm water containing a small quantity of hydrochloric acid, earthy alkalies and oxide of iron are extracted, while a final treatment with warm distilled water removes the hydrochloric acid in excess.

The simplest method is the purification with hydrofluoric acid. The carbon sticks are for this purpose placed in a leaden vessel provided with a lid and treated with hydrofluoric acid diluted with two parts of water during 24 to 48 hours at a temperature of from 15° to 25° C. They are then carefully washed with water, dried and baked for 3 to 4 hours.

Cylindrical carbons are now almost exclusively used; their dimensions vary with the system of lighting.

For arc lamps fed by the usual dynamos, carbons of from 7 to 10 millimetres (·273–·390 inch) are used; for powerful arc lamps for lighthouses and other naval purposes, for large projectors, carbons whose diameter sometimes reaches 20 millimetres (·78 inch) are employed.

For Werdermann's lamps, Jamin's and Jablochkoff's candles, carbons of from 4 to 5 millimetres (·156–·195 inch) are used.

§ 2. INTENSITY OF THE ARC AND DIRECTION OF LIGHT-RAYS.

In so far as the crater-shaped cavity of the upper positive carbon determines the direction of the rays, the light produced by a continuous current must necessarily have its greatest intensity in a downward direction.

According to Fontaine,* the maximum of intensity is observed at an angle of from 50° to 60° below the horizontal line. As a general formula for determining the intensity I_1 below the horizontal line we have

$$I_1 = I\,(5 \cdot 23 \sin a + 1)$$

where I is the intensity measured in a horizontal direction† and a the angle of deflection, formed by the horizontal line with the line giving the direction of the point for which the intensity is to be measured. We must always remember that the intensity is inversely proportional to the square of the distance of the illuminated point from the source of light.

Considering the dependency of the light intensity on the size and shape of the crater of the positive carbon, it is self-evident that the dimensions of the carbons and the shape of the points cannot be a matter of indifference. Now, the shape of the points is influenced by the arc; the longer the latter, the higher its resistance, the more heat it generates, the more pointed it becomes, and the smaller the incandescent area; whilst, on the other hand, a disproportionately small arc of low resistance causes over-heating of the other parts of the circuit, that is, of the windings of the dynamo. But, again, the resistance of a long arc can also be diminished by strengthening the current, and thus we meet everywhere with colliding interests, and are confined within narrow limits in order to reconcile them. One circumstance is most striking, namely, that the electric light radiates comparatively little heat,* while in its interior a very high degree of heat is generated; a gas flame, on the other hand, of much lower intensity gives off a much larger quantity of heat to the neighbourhood. This may be partly explained by the fact that the electric light yields no products of combustion, that its chemical process is not like that of the gaslight, maintained by the oxygen of the atmosphere; but this is only a partial explanation at best, and we have, in the case of electric light, certainly to deal with different conditions not only of light, but also of heat.

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* Fontaine, 'Éclairage à l'Électricité,' 2nd edition. Paris, 1879.

† The usual position of common photometers for determining light intensity.

Siemens assumes that, for the production of an electric light of 4000 candles, a current of 34 ampères is required; and that this intensity can be obtained with 200 Argand burners (20 candles each), which consume ·45 cb. in. of gas per minute. Taking the heat of combustion of 1 cb. in. of gas at 6335 calories, we get 2850 calories for ·45 cb. in. 34 ampères, produced in a circuit of 1·28 ohm total resistance, represent 21 calories per minute; adding to this 2 calories produced by the carbon consumed, we find that, for the production of electric light, not even *one* per cent. of the heat required for gas lighting is expended.

From an article in 'Engineering,' 18th Oct. 1878, we gather that the heat expended in the production of gaslight is to that of electric light as 139 : 1.

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* The radiated heat, however, cannot be neglected; for lights of average intensity it is already considerable, and large globes must be used to prevent their bursting. It has been found that a light of 300 to 400 candles radiates heat equal to 3 horse-power.

For the better comparison of the intensity of light obtained with continuous and alternating currents, we give in Fig. 35, a representation of the illuminating power of a naked light of 1700 candles.

The effect obtained with a continuous current is very small above the horizontal line, but with an alternating current, the same effect is obtained above and below the horizontal, leaving out of account the feeble effect of the arc in a lateral direction. We find that in the latter case a considerable portion of the light strikes on such places where no illumination is required for working purposes, and if amongst these latter there are areas which reflect the light badly, or disperse it too much on account of their height, this light effect is entirely lost for practical purposes, unless this loss is counteracted by special reflectors. On the other hand, the light produced by continuous currents generally corresponds to practical requirements, in so far as it shows its greatest intensity in a downward direction (10070 at an angle of 60°). For special cases, of course, the light of the alternating current may be preferable, even without special reflectors.

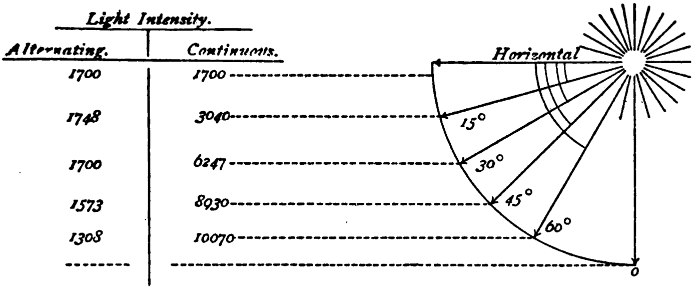

FIG. 35.

The illumination with Jablochkoff candles shows an entirely different result, as will be seen from Fig. 36.

The strongest light is directed upwards (653 candles). For the other directions we have to distinguish whether the light emanates from the flat surface or from the edge of the candle. The difference in horizontal direction is 585 and 425 candles respectively. The fact that the maximum intensity is here observed in an upward direction naturally led to arrangements for protecting the eyes against the dazzling effects of the light, and this is done either by entirely hiding the light from the sides and on the top, or, in the case of naked flames, by properly constructed reflectors. The enormous variations of intensity even for slight deflections from the horizontal line, the great difficulty of a perfect adjustment of carbons, the different qualities of these latter, the unavoidable variations resulting from even the most insignificant changes in the circuit, together with the inaccuracy of the usual method of measurement, naturally lead to the conviction, that figures and data on illuminating power of arc lamps must be received with the greatest caution, *in so far as they are intended to show the superiority of one system over another.*

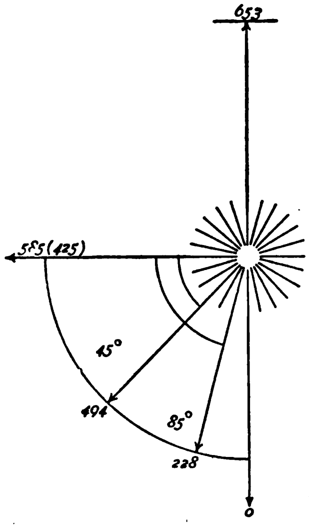

Fig. 36.

To show figures for an installation made under exceptionally favourable conditions is as easy as to detract from the results by taking up a hostile point of view.

The following page contains the results of photometric measurements made at the Paris Exhibition. It must not for one moment be thought that these measurements admit of a comparison between the different systems; they were in all probability made with the existing installations under different conditions of covering of the flames resulting in greater or lesser loss of light. So, for instance, opal globes absorb 60 per cent., frosted glass 30 per cent., and globes of the Siemens lamps, 20 per cent. of the incident light. These figures only present an interest in so far as they were obtained by careful measurements carried out by expert persons.

With an alternating Siemens machine, of 12·8 ampères, feeding twelve Siemens differential lamps in three circuits having carbon points of 10 mm. diameter, the light obtained was

In horizontal direction	330 candles.
Mean intensity	293 „

and consequently

Per mechanical horse power. . . .	250 candles.
Per electrical horse power	250 „
Per arc	310 „
Per ampère	27·45 „

Arc Lamps at the Vienna Exhibition.[*]

Only 3 kinds of arc lamps were tested at Vienna in 1883, and these were the Abdank, the Cance, and the Gravier. The following are the results obtained:

Name of Lamp.	Mean spherical intensity in candles.	Current in Ampères.	E. M. F. in volts.	Candles per electrical H. P.
Abdank .	785	11·69	49 69	992
Cance . .	293	6·46	48·83	684
Gravier .	767	7·90	49·49	1219

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[*] 'Bericht der wissenschaftlichen Commission,' Wien, 1886, p. 151.

ARC LAMPS AT THE PARIS EXHIBITION.

	Formula.	Siemens Machine. Feeding			Gramme Machine. Feeding			Brush Machine. Feeding 40 Lamps in Circuit.	Remarks.
		1	2	3	1	3*	5		
		Lamps in Circuit.			Lamps in Circuit.				
Current	Ampères	35	26·2	10	109·2	19	15·3	9·5	
Diameter of Carbon . .	Millimetres	18	14	10	20	14	12	11	
Horizontal light intensity.	Candles	1,575	1,065	502	7,140	1,162	840	472	
Maximum intensity . .	„	6,037	4,027	540	14,700	2,677	1,380	585	
Mean intensity	„ (l)	2,295	1,537	390	7,245	1,252	765	292	
Total mean intensity . .	L = ln	2,295	3,074	1,950	7,245	3,756	3,825	11,680	
Per mechanical Horse-power	L : H.-P.	517	579	386	450	464	479	391	For value of H.-P., h.p. and W., *vide* table p. 48.
„ electrical „	L : W	602	631	410	488	753	559	470	
„ arc	L : h.-p.	910	970	610	966	912	736	538	
ampère	l : C	65·55	58·65	39	66·38	65·93	50·03	30·83	

* Part of the current was said to have become ineffective by contacts within the electro-magnets.

*Arc Lamps at the Philadelphia Exhibition.**

It will not be without interest to describe the method used for measuring the light intensity of arc lamps employed by the Commission of the Philadelphia Exhibition, because they had at their command all the recent improvements, and all the experience gained by former Exhibitions at Paris, Munich and Vienna.

The lamp tests were chiefly made with regard to illuminating power from the horizontal plane up to 60° beyond this plane, and further, the current and E. M. F. at the lamp terminals were determined. Neither the regulating mechanism itself nor the resistance of the regulator coils was examined. All tests were made in a special locality fitted up for the purpose. Every lamp was fed by the dynamo which is in practice employed for the working of it, and the regulation and starting of the dynamo, as well as the current regulation were entrusted to the Exhibitor.

The light standard employed was a gas-burner of the Argand type which exactly represented two candles, and a Methuen screen.

Compared with the standard candles the gas-burner gave the same luminous intensity in a much more uniform manner. It was placed at the extremity of a photometric ruler, 450 centimetres in length, at the other extremity of which was placed a Swan lamp of 50 candles, serving as secondary standard. This lamp was fed by a Brush accumulator. A second graduated ruler, forming a small angle with the former, went from this lamp into an adjoining room where the arc lamp to be examined was suspended. In order to be able to examine the light emitted by the

* *La Lumière Electrique*, No. 35, p. 418. 1885.

arc lamp at different angles with the horizontal line, the arc lamp was suspended at the extremity of an arm movble about a horizontal axis parallel to the photometric ruler, but placed in a vertical plane passing through this ruler, so that, when the arm was in a horizontal position, the arc of the lamp suspended at its extremity was at the same height as the centre of the photometer disc.

On raising the extremity of the arm the luminous point consequently traced a vertical circle round an axis formed by a line passing through the centre of the photometer disc and parallel to the ruler. The radius of this circle was 127 centimetres, and its plane was 640 centimetres from the secondary standard. In the centre of the circle was placed a glass mirror whose reversed side was silvered, so that the light of the arc lamp was reflected on the photometer disc in the direction of the axis of the circle. It will be seen that the distance between the lamp and the mirror was constant for every position of the arc lamp, that, the mirror once adjusted for reflecting the light on the disc, the angles of incidence and of reflection were always 45°, and that, finally, the distance between the image of the arc lamp and the secondary standard was always 767 centimetres. The absorbing power of the mirror was carefully determined, and was taken into consideration in the calculation of the results.

The manner of proceeding was generally as follows: The arm carrying the arc lamp was placed horizontally, and the height of the lamp was regulated in such a manner as to place at the same level the luminous point, the centre of the mirror, and that of the photometer disc. Two observers regulated ten times the position of the two discs. The extremity of the arm and the lamp suspended to it were then raised, and the observations repeated. The same operation was started several times, so as to determine a sufficient number of positions. During the photometer readings the current and the E. M. F. were frequently measured.

In order to facilitate the comparison between the arc lamps and the standard, an apparatus was used, by means of which half the light or even a larger fraction of it could be eliminated at will. This apparatus consisted of a brass disc of a diameter of about 30 centimetres, and provided with 24 perforations in form of a sector, equal to one another and to the intervening unperforated parts. Another absolutely similar disc was placed over the former and could be turned so as to obstruct any part of the perforations. This apparatus was mounted on an axis arranged in such a manner as to compel the light of the arc lamp to pass through the perforations before arriving at the photometer disc. The rotation of the apparatus, even at a moderate speed, produced no sensible variation in the light.

For the experiments of the Commission the apparatus was employed with open sectors it then suppressed theoretically half the light.

Experience has shown that, if an error is committed, it is considerably slighter than that produced by the oscillations of the electric axis.

The following table contains the results of all the tests. (See pp. 158, 159.)

The *total efficiency resulting from practical working* is the only criterion for a final judgment, the possibility not being excluded, that even the most ingenious and theoretically most perfect arrangements may show no superiority, in so far as they contain conditions which are incompatible with practical working. It may even happen that we have to

ARC LAMPS AT THE PHILADELPHIA EXHIBITION.

Lamps.	Height.	Candles.	Ampères.	Volts.	Energy in the Lamps.		Results reduced.			Remarks.
					Watts.	H. P.	Height.	Candles.	Candles per H. P.	
Arago	Horizont.	273	15·44	39·87	614·4	·824	Horizont.	273	332	15 lamps in circuit.
	15° 30′	356	„	„	„	„	15°	350	425	
	30° 15′	505	„	„	„	„	30°	465	565	
	44° 30′	557	„	„	„	„	45°	583	708	
	56° 40′	644	„	„	„	„	60°	645	783	
Ball	Horizont.	233	6·60	48·83	322·3	·432	Horizont.	233	539	17 lamps in circuit.
	19° 19′	431	„	„	„	„	15°	380	880	
	35° 05′	534	„	„	„	„	30°	520	1,204	
	46° 25′	346	„	„	„	„	45°	485	1,123	
	60° 00	284	„	„	„	„	60°	182	421	
Brush (1200) . .	Horizont.	180	6·62	52·50	347·5	·466	Horizont.	180	386	One single lamp in circuit; light very steady.
	„	118	„	„	„	„	„	118	253	
	10° 26′	266	„	„	„	„	15°	332	712	
	22° 11′	439	„	„	„	„	30°	537	1,152	
	37° 30′	617	„	„	„	„	45°	613	1,316	
	47° 00′	597	„	„	„	„	60°	355	762	
	56° 35′	422	„	„	„	„	„	„	„	
Brush (2000) . .	Horizont.	389	10·32	56·73	585·5	·785	Horizont.	389	496	One single lamp in circuit.
	12° 16′	575	„	„	„	„	15°	613	819	
	22° 11′	842	„	„	„	„	30°	1,082	1,379	
	32° 00	1,253	„	„	„	„	45°	1,378	1,750	
	58° 40′	1,246	„	„	„	„	60°	1,200	1,529	

Diehl	Horizont.	323	17·67	31·84	562·6	·754	Horizont.	323	428	4 lamps in circuit.
	26° 10′	673	„	„	„	„	15°	496	658	
	38° 30′	809	„	„	„	„	30°	725	961	
	56° 40′	881	„	„	„	„	45°	830	1,101	
	„	„	„	„	„	„	60°	887	1,176	
Richter . . .	Horizont.	313	20·19	30·00	605·7	·812	Horizont.	313	386	6 lamps in circuit. Light very irregular. Feeding of carbons periodical; current is nearly zero and rises to 25 amp., falls then to 10–18 amp., and finally to zero.
	14° 30′	691	„	„	„	„	15°	700	862	
	29° 15′	956	„	„	„	„	30°	960	1,183	
	44° 25′	813	„	„	„	„	45°	894	1,101	
	50° 30′	986	„	„	„	„	60°	603	743	
	57° 24′	633	„	„	„	„	„	„	„	
Van de Poële (20-light dynamo) .	Horizont.	451	16·91	37·88	640·5	·858	Horizont.	451	525	One single lamp in circuit. The lamp had to be frequently regulated by the exhibitor.
	15° 00	701	„	„	„	„	15°	708	825	
	28° 40′	1,020	„	„	„	„	30°	1,060	1,235	
	46° 25′	1,377	„	„	„	„	45°	1,377	1,664	
	56° 24′	848	„	„	„	„	60°	670	780	
Van de Poële (60-light dynamo) .	Horizont.	333	13·31	45·77	609·2	·817	Horizont.	333	408	One lamp in circuit. Light very irregular; frequent and considerable oscillations.
	16° 00	700	„	„	„	„	15°	535	655	
	34° 00	890	„	„	„	„	30°	900	1,101	
	46° 25′	1,156	„	„	„	„	45°	1,162	1,423	
	57° 24′	606	„	„	„	„	46°	500	612	
Western Electric .	Horizont.	263	17·89	25·74	460·5	·617	Horizont.	263	426	22 lamps in circuit.
	30° 30′	355	„	„	„	„	15°	330	523	
	35° 15′	340	„	„	„	„	30°	355	575	
	46° 30′	247	„	„	„	„	45°	266	431	
	52° 00	183	„	„	„	„	60°	75	121	

ARC LAMPS AT THE PHILADELPHIA EXHIBITION.

Lamps.	Height.	Candles.	Ampères.	Volts.	Energy in the Lamps.		Results reduced.			Remarks.
					Watts.	H. P.	Height.	Candles.	Candles per H. P.	
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	30° 15′	505	”	”	”	”	30°	465	565	
	44° 30′	557	”	”	”	”	45°	583	708	
	56° 40′	644	”	”	”	”	60°	645	783	
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	19° 19′	431	”	”	”	”	15°	380	880	
	35° 05′	534	”	”	”	”	30°	520	1,204	
	46° 25′	346	”	”	”	”	45°	485	1,123	
	60° 00	284	”	”	”	”	60°	182	421	
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	”	118	”	”	”	”	”	118	253	
	10° 26′	266	”	”	”	”	15°	332	712	
	22° 11′	439	”	”	”	”	30°	537	1,752	
	37° 30′	617	”	”	”	”	45°	613	1,316	
	47° 00′	597	”	”	”	”	60°	355	762	
	56° 35′	422	”	”	”	”	”	”	”	
Brush (2000) . .	Horizont.	389	10·32	56·73	585·5	·785	Horizont.	389	496	One single lamp in circuit.
	12° 16′	575	”	”	”	”	15°	613	819	
	22° 11′	842	”	”	”	”	30°	1,082	1,379	
	32° 00	1,253	”	”	”	”	45°	1,378	1,750	
	58° 40′	1,246	”	”	”	”	60°	1,200	1,529	

Diehl	Horizont.	323	17·67	31·84	562·6	·754	Horizont.	323	428	4 lamps in circuit.
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	38° 30′	809	”	”	”	”	30°	725	961	
	56° 40′	881	”	”	”	”	45°	830	1,101	
	”	”	”	”	”	”	60°	887	1,176	
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	14° 30′	691	”	”	”	”	15°	700	862	
	29° 15′	956	”	”	”	”	30°	960	1,183	
	44° 25′	813	”	”	”	”	45°	894	1,101	
	50° 30′	986	”	”	”	”	60°	603	743	
	57° 24′	633	”	”	”	”	”	”	”	
Van de Poële (20-light dynamo) .	Horizont.	451	16·91	37·88	640·5	·858	Horizont.	451	525	One single lamp in circuit. The lamp had to be frequently regulated by the exhibitor.
	15° 00	701	”	”	”	”	15°	708	825	
	28° 40′	1,020	”	”	”	”	30°	1,060	1,235	
	46° 25′	1,377	”	”	”	”	45°	1,377	1,664	
	56° 24′	848	”	”	”	”	60°	670	780	
Van de Poële (60-light dynamo) .	Horizont.	333	13·31	45·77	609·2	·817	Horizont.	333	408	One lamp in circuit. Light very irregular; frequent and considerable oscillations.
	16° 00	700	”	”	”	”	15°	535	655	
	34° 00	890	”	”	”	”	30°	900	1,101	
	46° 25′	1,156	”	”	”	”	45°	1,162	1,423	
	57° 24′	606	”	”	”	”	46°	500	612	
Western Electric .	Horizont.	263	17·89	25·74	460·5	·617	Horizont.	263	426	22 lamps in circuit.
	30° 30′	355	”	”	”	”	15°	330	523	
	35° 15′	340	”	”	”	”	30°	355	575	
	46° 30′	247	”	”	”	”	45°	266	431	
	52° 00	183	”	”	”	”	60°	75	121	

reject in one place an arrangement which works admirably in another, because the mode of treatment was different. Experience in *one* place cannot alone decide the practical value of a system, and hence it is unavoidable that, in different places, different systems will be adopted. One fact however is clearly manifest from the above considerations, namely, the superiority of the continuous current machine for the production of arc light.

Classification of Arc Lamps.

All arc lamps utilize the variations produced in the current to act upon the mechanism which regulates the distance of the carbons. In certain arc lamps only *one* light is fed by a given electrical source. In others, two, four, and up to forty are supplied by the same current. We accordingly divide all arc lamps into single-light (monophotal) and polyphotal, or division lamps.

§ 3. MONOPHOTAL OR SINGLE-LIGHT ARC LAMPS.

All single-light arc lamps present this common characteristic feature, that the electromagnetic system which produces the adjustment of the distance of the carbons is placed in the same circuit as the arc itself. The regulating apparatus is therefore traversed by the whole of the current, and the variations in the strength of the current cause the approach or withdrawal of the carbons.

The classification in itself is not of much importance, since these lamps can by a simple contrivance be converted into polyphotal lamps; it has been adopted in this book, in order not to have too large an amount of material under one heading.

1. *Foucault-Duboscq Arc Lamp.*

We have already mentioned that the first arc lamp with automatic regulation was constructed by Foucault, and we are now going to describe the latest form of this lamp as improved by Duboscq, and applied by him to demonstrations in Physics, but not for lighting purposes.

In the improved form, shown in Fig. 37, an arrangement is introduced for the automatic relighting of the arc in case of extinction. In the clocktrain are two barrels L and L¹ and two systems of wheels ending in the two fly wheels *o* and *o*¹. Wheel *s* checks the one system of wheels as soon as it releases the other. Between the two fly wheels *o* *o*¹ is a detent *t* which is

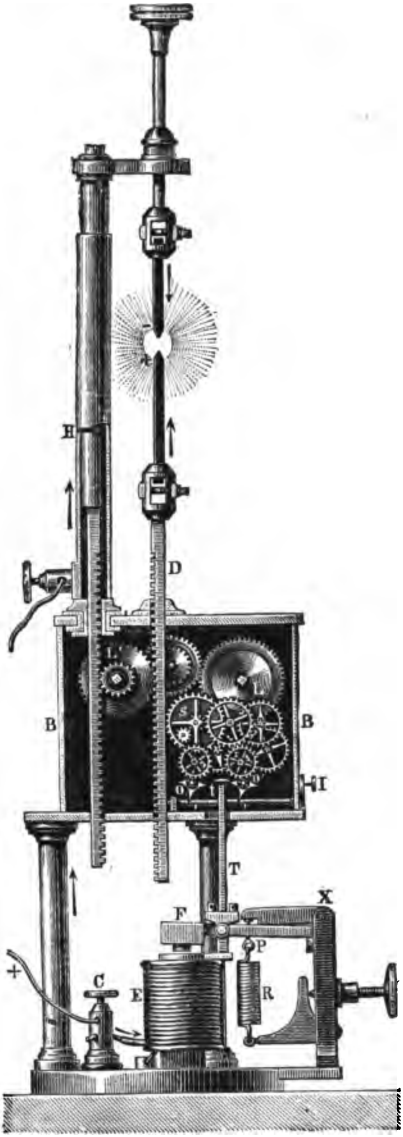

FIG. 37.—FOUCAULT-DUBOSCQ'S LAMP.

in solid connection with the armature F of the electro-magnet E, and, following its movements, gears in alternately with *o* and o^1. The system of wheels ending in *o* brings the carbons together, the one ending in o^1 draws them apart. Armature F is controlled by means of the spiral spring R fastened to a lever movable about *x*.

The positive current entering through the terminal C traverses the windings of the electro-magnet, and then flows through the metallic parts of the apparatus into rackwork D, to the lower carbon, whilst the wire of the negative pole connected to the terminal of tube H leads to the negative carbon.

When no current passes, the detent *t* gears in with fly-wheel o^1. If now the springs of both barrels L and L^1 are wound up and released, the two carbons approach each other until they touch, the entering current causes the attraction of armature F and the detent *t* is removed to *o*, while the system of wheels in connection with o^1 is released, and the carbons withdraw from one another. If the normal length of the arc is exceeded, armature F, in consequence of the weakening of the current, draws back, detent *t* is displaced to o^1, etc., so that by the backward and forward movement of the detent lever T, the normal length of the arc is preserved. The construction is ingenious, but rather complicated, and therefore exposed to frequent disarrangements. A further drawback is that it must always be wound up before being used.

2. *Archereau's Lamp.*

In Archereau's apparatus the upper (positive) carbon is fixed, the lower (negative) carbon rests on a cylinder made half of iron and half of copper. This cylinder is placed in a solenoid, which is traversed by the current and kept in equilibrium by a counter weight. The action of the solenoid produces and maintains the distance of the two carbons by exercising its sucking action on the iron rod provided the proportions between the power of the solenoid, the weight of the rod and the strength of the current are carefully established. This lamp too has more of a historical than a practical interest.

3. *Jaspar's Lamp.*

This apparatus consists of two movable carbon-holders K and K^1 (Fig. 38). The negative carbon holder K^1 is formed of a copper tube ending in a hollow cylinder of soft iron. In the middle the tube K^1 is pierced with a longitudinal slit wide enough to allow a grooved pulley to pass; around this pulley is wound a cord which descends in the axis of tube K^1 and carries a weight G that keeps it stretched. This weight abuts upon a transverse piece in such a way that when the cord is wound up, the weight in rising lifts the carbon-holder. The grooved pulley is fixed on a small drum, on which is also placed a second grooved pulley, having a diameter double that of the former. On the latter is wound a cord attached to the lower extremity of the positive carbon-holder K, and it also carries a counterpoise. It will be seen that, by the direction in which the cords are wound, the weight of the positive carbon-holder tends to raise the negative carbon-holder, and that this latter will move through only half the distance of the former. This difference corresponds to the unequal waste of the carbons. The positive carbon-holder is formed of a copper tube K, furnished with a clip to which the carbon is attached. The carbon is held securely in place by a locking screw.

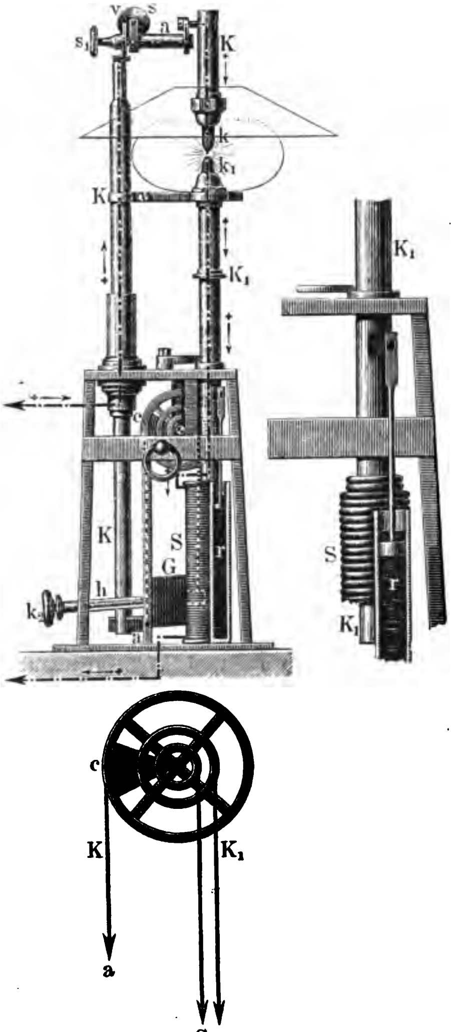

FIG. 38.

The negative carbon carries a pendent rod, terminating in a small piston which can move within the tube *r* filled with mercury forming what is known as a *dashpot.* The diameter of the piston is less than that of the tube, so that when the piston moves down by the motion of the carbon-holder, the mercury passes from one side to the other of the piston by the narrow angular space. This acts as a very efficient brake, and prevents any sudden action which would show itself in irregularity of the light. On the tube *s* is wound an insulated copper wire forming a solenoid, and intended to produce the separation of the carbons, and to counterbalance the effect resulting from the weight of the positive carbon-holder.

When at rest the carbons are in contact. At the moment when the current passes, the solenoid attracts the iron core of the lower holder, and retains the carbons at the proper distance. When the arc is lengthened, the current is weakened, and the carbons acted on by the weight of the holder K are drawn slightly nearer to one another. The counterpoise G acts in an opposite sense to the holder K, since, by the windings of the cords, it tends to produce a withdrawal. The adjustment is therefore easily obtained by the displacement of the weight G. The more intense the current, the nearer the weight G must be to the point where the cord is attached.

The action of the solenoid on the carbon-holder K^1 is not the same at the end as at the beginning. This difference of action is compensated for by the small counterpoise, and which is regulated by its distance from the centre. At the beginning the counterpoise *c* has no action; at the end its weight is added to that of the weight G to counterbalance the action of the solenoid.

This lamp is of very simple construction. It attracted much attention at the Paris Exhibition of 1881, and is much used in Belgium.

For better utilization of light, Jaspar uses reflectors of different kinds, and also movable lenses and mirrors which throw the light rays in the direction where they are required for working purposes. In this way he effects a distribution of light without giving up the advantages of a monophotal lamp. An installation made at the Brussels Telegraph Office has given most satisfactory results.

4. *Jürgensen's Lamp.*

In this lamp the movements of the carbons are regulated by the differential action of two solenoids, tending, the one to the withdrawal, the other to the approach of the carbons. The apparatus is represented in Fig. 39, which explains the principle of its working.

The two regulating solenoids are placed at S^1 and S; they have soft iron cores, terminating in the carbon-holders. In addition to the solenoids, a small special arrangement is provided, represented in detail in the centre of Fig. 39, for lighting the lamp when the carbons are not in contact. Supposing the two carbons to be apart from one another, the current enters through the terminal P +, and arriving at the piece *t* cannot energize the electro-magnet E for the circuit is broken at k_1; the armature *a* of this latter will therefore remain apart, and the current, passing through the piece *t*, the screw *s*, the armature *a*, and the piece *t*, will traverse the solenoid S_1 and return to the terminal P—. The solenoid S_1, acting on the soft iron of the carbon-holder *e*, will lower it, and *e* being raised at the same time, contact of the two carbons will be produced. At this moment part of the current will pass through the electro-magnet E, the armature of this latter will be attracted, and the contact at *s* broken, so that the current will no longer be able to pass

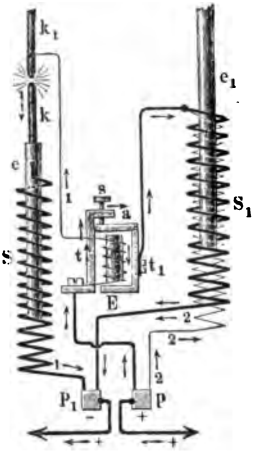

FIG. 39.

from *t* to S_1, but its main path will be from P +, through E, through the two carbons and the solenoid S to P—. The solenoid S will then begin to act, and will bring about the withdrawal of the carbons and the production of the arc.

When once the arc is established, and as long as it is maintained, the lamp may be considered a differential lamp. On the upper part of the solenoid S_1 is, in fact, branched another solenoid of great resistance. The two solenoids combined form, when the contact at *s* is broken, a solenoid of great resistance placed in a shunt between the two terminals of the lamp. It will now be clear how the regulation is effected. When the arc acquires too great a resistance, more of the current passes into S_1, K is lowered, and the carbons approach one another. In the opposite case the action of S becomes preponderating, and a withdrawal is the result.

The natural tendency of the carbons to effect an approach is further regulated by a little drum containing a spring. This spring has the same function as the adjusting weight of Jasper's lamp, to which the Jürgensen lamp bears a great resemblance.

For a current of from 14 to 14·7 ampères, which is generally sufficient for the lamp, the difference of potential at the terminals of the lamp was found to be 41 to 42·5 volts, and the work expended in the arc 60·6 to 61·44 kilogrammetres (605 Watts). The luminous intensity is about 200 carcels (1,900 candles), which would give about ·4 kilogrammetre (3 Watts) for one carcel.

5. *Siemens and Hefner-Alteneck's Monophotal Lamp.*

In the lamp (Fig. 40) the rack-works Ż and Z_1 of the two carbon holders act on the wheels *r* and r_1, in proportion to the waste of the carbons, *i. e.* in proportion of 8 : 5. The motion is transmitted to a ratchet provided with a detent piece *w w*, whose course can be arrested by a check fastened to the lever *h*. The latter is in solid connection with the armature *a* of the electro-magnet E. The screw S regulates a spring fastened to the lever *h*, the lever and therefore the armature *a* as well, is thereby brought back to its position of rest when no current passes. c c_1 is a contact opened or closed by the motion of the lever, the oscillating part *c*, as well as one end of the electro-magnet winding being in electrical connection with the metallic body of the lamp. At the commencement of working, the wheel-train is released by a special contrivance, and the two carbons k and k_1, are thereby brought into contact. The positive current entering through *c*, (c_1, and z_1, are insulated from the lamp case and also wheel *r*, into which z_1 gears in, from its axle) passes, when the contact c c_1 is open, through the electro-magnet, the metallic body of the lamp, the upper carbon-holder, through both carbons and the rackwork z_1, back to the

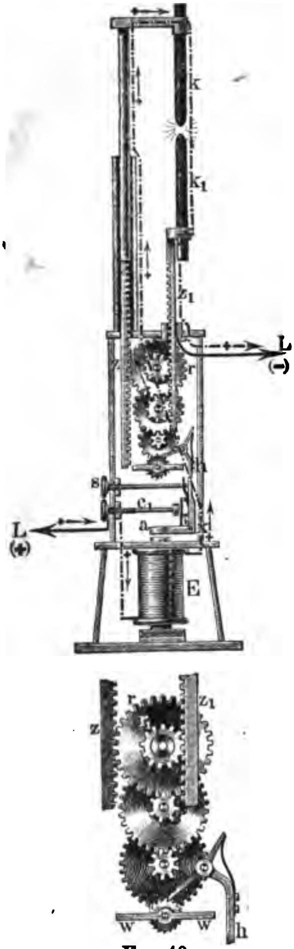

Fig. 40.

electric source. The passing current is strong enough to attract the armature *a*; the check attached to lever *h*, now gears in with the opposite ratchet wheel and turns it back by one tooth, thus bringing about a withdrawal of the carbon and the formation of the arc. The motion of lever *h*, however, closes the contact $c\ c_1$, and a shorter path is thereby offered to the current, the electro-magnet becomes inert, the armature withdraws, and the carbon points approach each other through the action of the wheel train. This effect, however, is only of short duration, because, through the withdrawal of the armature the contact $c\ c_{1+}$ is opened afresh, and the current again finds its way through the electro-magnet. Thus the play repeats itself in rapid succession and a normal length of the arc is approximately preserved, corresponding to the tension of armature *a*, or its distance from the cores of the electro-magnet.

The light, as in Foucault's arc lamp, remains at the same height, the construction is simple, and the working steady.

6. *Bürgin's Lamp.*

The original model of this lamp (Fig. 41) was constructed to give a single light only. *e e* are two arms of an electro-magnet joined by the lamp case; these are opposed by the armature *a*, which is likewise wound with wire and therefore also constitutes an electro-magnet. This latter is movable, and fastened to the lamp case by two arms $a_1\ a$, it carries a wheel *r* movable round its axis. A small chain leads from this axis over the pulley *r*, to the upper carbon-holder *k*, which is thus compelled to follow the movements of wheel *r*. This motion however can only commence when the spring *f* sliding on the circumference of the wheel is withdrawn from action.

The positive current on entering the lamp branches off, on the one hand through the windings of the electro-magnet *e e* and both carbons, on the other hand through the windings of armature *a* and both carbons. The armature windings are connected in such a way, that the two poles formed by the current are magnetized in an inverse sense to the opposed electro-magnet cores. The attraction is now so powerful that, upon the entrance of the current, the armature *a* with the wheel *r* is raised. This latter is now pressed against the springs, and thus prevented from turning, whilst through the simultaneous raising of the upper carbon the arc is formed. This position is preserved as long as the arc keeps its normal length. As the carbons are consumed the arc is lengthened, the attraction of the electro-magnet is weakened, and the armature *a* sinks down. The pressure of spring *f* being thus diminished, the upper carbon descends by its own gravity until the normal length of the arc is reached. And now recommences the raising of the armature *a* and the arrest of wheel *r*, etc.

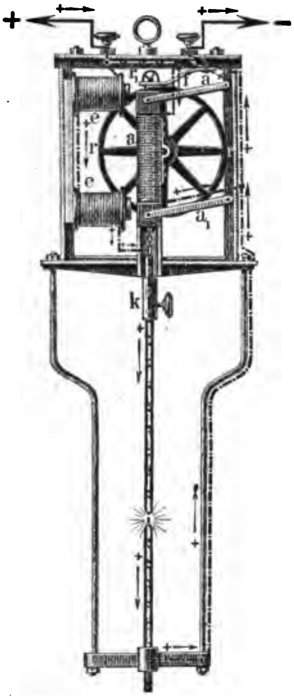

Fig. 41.

The lamp thus constructed is monophotal; if two or more lamps are to be burned in one circuit, the shunt current, passing through the armature windings, is led off directly to the negative pole instead of the carbons, as is indicated by the arrows in our sketch. In this case, the armature windings receive such a high resistance that their magnetizing effect only becomes noticeable when, through an increase of resistance in the electro-magnet circuit, the current increases in the other branch; the armature winding is here connected in such a way that poles of the same name are opposed to the electro-magnets *e e*. The current action is essentially the same as in the monophotal lamp; armature *a* and wheel *r*, as well as the upper carbon, are raised by the attractive action of the electro-magnet, and this position is preserved for a normal length of arc; if this is exceeded, the current is strengthened in the armature windings, the opposed poles of equal name repel each other, the movable armature sinks down, and wheel *r* is freed for motion, the normal length of arc is restored, and the armature is attracted anew by the electro-magnets.

This lamp has found a most extensive application in Switzerland, South Germany and Austria. It is specially claimed that, on account of its great simplicity, the lamp can be used in the open air in all seasons, as well as in the dusty atmosphere of mills and factories.

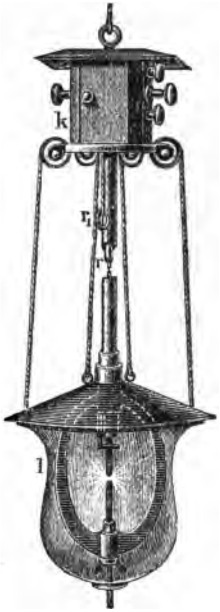

FIG. 42.

In Fig. 42 we show the suspension lamp used in the open air. It consists of a case *k* containing the regulating apparatus, a guiding tube *r* for the upper carbon-holder, and the lantern *l*. To protect the lamp from rain, snow, etc., the case has a roof, and the lantern a conical screen which at the same time acts as reflector, while a crystal globe screens the arc from the influence of the wind. Screen and globe are suspended by strings passing over pulleys in such a way that, on raising the former, the latter is lowered, a very convenient arrangement for the necessary change of carbons. The ring r_1 which is suspended to the guiding tube, is joined by a string to the axis of wheel *r* (Fig. 42) and serves for raising the upper carbon-holder.

The resistance of the windings of the electro-magnet *e e*, inclusive of the resistance of the arc, amounts to 1 to 3 ohms, that of the armature windings to several hundred ohms. The two screws near the top and bottom of the case (Fig. 42) serve for regulating the length of arc, while the two screws in the middle are used as terminals. Carbons of 13 mm. diameter and 50 cm. length burn eight hours, with a current of 20 ampères. After the consumption of the lower carbon, it is replaced by the remaining portion of the upper carbon, whilst this latter is replaced by a new carbon stick.

For lighting up halls, concert-rooms, etc. highly ornamental forms are used, provided with opal glass globes of ·5 metre diameter. The lamps fed by the Bürgin dynamo gave the following results :—

	Candles per H.P. and per lamp.
For single light	1200
2 lamps in circuit	1100
3 „ „	1100
4 „ „	1000
5 „ „	850

and according to other tests—

	Current in ampères.	Candles per H.P. and per lamp.
3 lamps in circuit . .	20 . . .	1600
3 „ „ . .	21·5 . . .	2310
4 „ „ . .	18·2 . . .	1120
4 „ „ . .	16 . . .	1840

Quite lately Bürgin has patented a lamp with a double carbon, whose regulation does not materially differ from that of the above type. The lighting of the carbons, as well as the insertion of a second pair of carbons on consumption of the first, is effected by a similar contrivance as in the Brush lamp (v. p. 198).

7. *Crompton's Lamp.*

Amongst the arc lamps used in this country the Crompton lamp has been one of the most successful. Like the Bürgin lamp, it was first constructed as a monophotal lamp, and afterwards modified and changed into a differential lamp. Both types are described in this place.

a. *Monophotal Lamp.*

Through a cylindrical case *g g* (Fig. 43) in whose upper part the regulating apparatus is enclosed, protrude the two carbon-holders K K_1, the former supplying, by its own weight, the motive power for the clocktrain by acting on the grooved pulley *r*, which transmits its motion to the wheels r_2 r_3 *r*. Carbon-holder k_1 is hollow, and contains a rod k_2, to which is fastened by means of a number of jointed connections *r* the lower carbon k_1; the relative position of the two carbons is further controlled by the spiral spring *s*, while the upper carbon *k*, freely protruding out of the case, descends together with the holder K.

E is an electro-magnet whose movable armature *a* carries a very thin plate joined to a steel spring *f*. Armature *a* is at the beginning of working attracted by the strong passing current, and in the regular course only recedes, under the influence of spiral spring *s*, when the current is interrupted. The variations of current strength during work manifest themselves in vibratory motions of the armature plate and the spring *f*. During these vibrations, and according to the strength of the passing current, the latter begins to press on wheel *r*, and arrests the motion of the clocktrain; the regulation of the clocktrain is effected by a sliding spring *f*, controlled by screw s_2. Experience shows that the arrest of wheel *r* by vibrating spring takes place eight to ten times during an entire revolution, and that the distance through which the carbon *k* descends is ·1 mm., so that for one single motion only from ·0125 to ·01 mm. of fresh carbon enters the arc. There can be no question that this special regulating arrangement contributes in no small degree to the steadiness of the arc. When no current passes, the upper carbon descends until it touches the lower one;

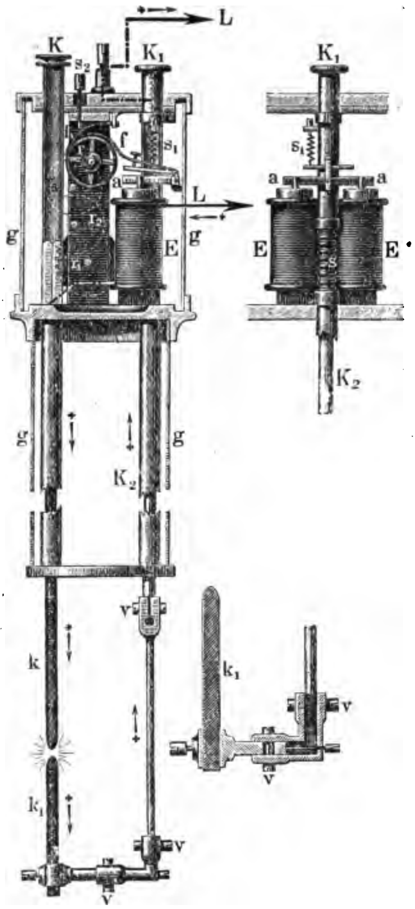

FIG. 43.

as soon as the current enters the lamp, armature *a* brings about a reverse motion of the clocktrain, and the upper carbon is raised and the arc formed. The arc is only a few millimetres long, and can, considering the very sensitive method of regulation, not be perceptibly lengthened. The longer the arc the richer it is in violet and purple rays, and the most desirable pure white light can only be obtained by a short arc.

The length of carbons allows from six to eight working hours, and, in order to maintain a uniform resistance, a sliding contact is contrived within the hollow tube *k*, which materially assists the connection of leads and carbons.

If several lamps are to be placed in one circuit, the mechanical regulation by means of spring *s* is replaced by a small electro-magnet of from 80 to 100 ohms resistance, which is interpolated in the circuit, and thus controlled by the passing current.

Four Crompton-Bürgin (three-light machines) fed twelve lamps (three in one circuit), each of which, for 1½ H.-P. expended gave 4,000 candles, and lit up an area of 1,700 square metres.

The largest circuit, inclusive of return wires, had a length of 530 metres, and the conductors consisted of uninsulated copper wire of 4·3 mm. diameter.

The three lamps of one circuit placed in series had,

inclusive of carbons and arc, a resistance of	9·36 ohms.
the resistance of the machine was	2·80 ohms.
„ „ „ conductors	1·10 ohms.
Total resistance ..	13·26 ohms.

The resistance of carbons and windings of regulating apparatus was ·60 ohm, the resistance of the three arcs therefore $9 \cdot 36 - \cdot 60 = 8 \cdot 76$ ohms, and of each arc $= \frac{8 \cdot 76}{3} = 2 \cdot 92$ ohms. The current, at 1,500–1,600 revolutions per minute and 200 volts E.M.F. $= \frac{200}{13 \cdot 26} = 15$ ampères. The work done by the current (v. p. 46) is according to Joule's law $= C^2R$, in our case $= 15^2 \times 2 \cdot 92$; and the product divided by horse-power expressed in kilogrammetres (75) and gravity in metres (9·81) gives the energy expended in the arc $= \frac{15^2 \times 2 \cdot 92}{75 \times 9 \cdot 81} = \cdot 89$ H.P.

An arrangement had been made, by which, on the extinction of one lamp, an artificial resistance, equal to that of the short-circuited apparatus, was automatically introduced. This purpose was effected by the release of the armature of an electro-magnet, which during the working of the lamp had been attracted, and, by its release, closed a contact, and thus opened for the current a new path containing the artificial resistance.

b. Polyphotal Lamp.

The latest form of this lamp is represented in Fig. 44. The upper carbon *k* is by means of a screw joined to the weight *w*, and passes through the bottom of the closed lamp case, being insulated from it by an earthenware ferrule. The weight *w*, sliding between two guiding rods *ss*, is suspended to a cord or chain which passes over the pulleys r_1 r_2 r_3, through the hollow rod *g*, over three pulleys of the cylindrical case of the lower carbon (not shown in the figure), and finally to the clip holding the carbon. The latter is thus compelled to follow the motion of the upper carbon in an opposite direction. This motion is regulated by a small clock-train $r_4\,r_5\,r_6$, which is arrested or released by the action of the current, and whose frame is in solid connection with the movable articulated lever *h*. A pulley r_2 is fastened on the axle of the wheel r_4, and a brake-wheel is connected with the axle of the wheel r_6. A small brake *b* presses by means of a spring against the brake-wheel and is fastened to a horizontal lever *h*, which is opposed to the movable iron core *e* of a double spiral SS_1. S is wound with fine, and S_1 with coarse wire, and S_1 as usual lies in the main current, while S is placed in a shunt. The carbons at the commencement of working are in contact; the passing current lowers the iron core *e*, and with it the frame of the clock-train, the clock-train itself and the pulley r_2. The chain passing over the pulley is thereby tightened and the carbons withdrawn from one another for the formation of the arc.

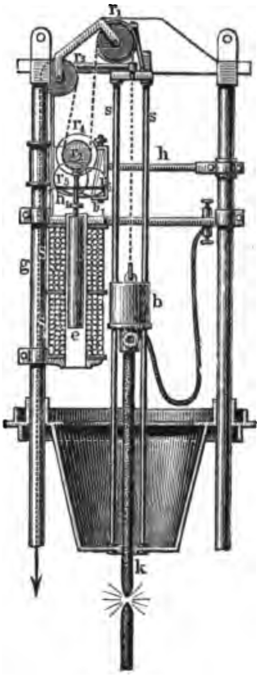

FIG. 44.

The consumption of the carbons increases the resistance of the main circuit, the current in the shunt coil *g* is thereby strengthened and the iron core is raised. The carbons now draw together, and the arc is shortened until the lever *h* is arrested by a stop fastened to the lamp frame and releases the clock-train.

The adjustment of the lamp is effected by two methods: either the weight *b* can be increased or decreased according as the lamp burns with too long or too short an arc, or the position of the stop can be altered by placing it higher or lower according as the arc is too short or too long. The lever *h*, is set into a continuous vibratory motion, so that the slightest variations of the length of the arc are immediately adjusted.

The position of the arc varies very slightly in this lamp.

The construction of the lamp can be modified in two ways:—

The two coils S & S_1 can be placed alongside of each other, each having a separate movable iron core, or an electro-magnet can be used instead of the two coils, whose two limbs are wound for a differential effect.

Five such lamps, with a moderate length of conducting wires, can be maintained in one circuit by a Crompton machine running at a speed of say 1,650 revolutions per minute.

The internal resistance of the machine is about 4 ohms. The current required to work the lamps is from 18 to 20 ampères. The E. M. F. of the machine is 280 volts, leaving 200 volts for external circuit, which makes it 40 volts per lamp. Intensity of light between 2,000 and 2,500 candles for horizontal, and between 2,500 and 4,000 candles for downward, rays.

10. *Solignac's Lamp.*

We only mention this lamp for the sake of the originality and simplicity of its regulation. While in all other arc lamps the current itself performs the regulating functions, Solignac transfers them to the heat generated in the arc. Figs. 45 and 46 show the details of the apparatus.

Two carbons *c c*, about 19 inches long, are placed nearly horizontal, and with their ends in contact. Their movement is regulated by a system of chains *k k*, which pass over the pulleys *r r* attached to the free end of the carbons, and over the pulleys *f f*, fastened to the frames *a a*, and thence to a weight, always tending to keep the ends of the carbons in contact. Beneath each carbon is a glass rod *g* (Fig. 46), the ends being curved and butting against a nickel stop *n*, the position of which can be adjusted by the screw f_1. The current is brought to the carbons by the rollers *w w*, carried at the end of a bar attached to the frame. The distance of the carbons is regulated by means of the screw *s*.

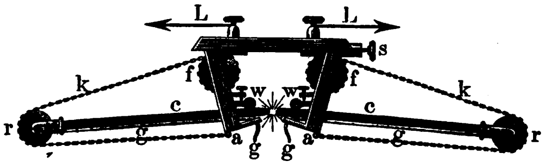

FIG. 45.

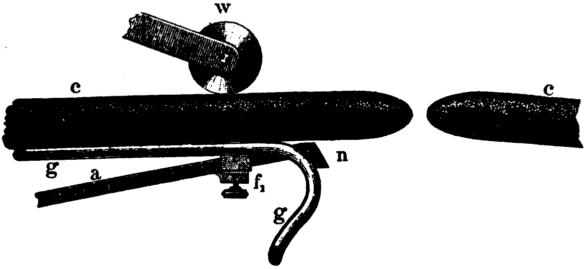

FIG. 46.

The action of this lamp is as follows:—The arc being established, the incandescent cone generally approaches the ends of the glass rods, and softens them in such a way that they yield under the pressure of the weight attached to the system of cords *k*. Curling under the nickel stop *n* as shown, they allow the carbons to approach, and so the arc is constantly maintained.

That this is the simplest system of arc lamp that has yet been invented is beyond doubt; its practical usefulness, however, has not been tested.

Solignac has provided his lamp both with a regulating and relighting apparatus, the former being placed at a distance.

We herewith conclude the list of monophotal lamps. A large number of these apparatus have been constructed and patented since the question of electric lighting has become a practical one. The most prominent and most practical of them have been mentioned in this paragraph; they all rest on the same principles. The approach of the carbons is brought about by the mechanical effect of gravity, and the regulation of the apparatus—that is to say, keeping the carbons at the convenient distance for the maintenance of the arc—is performed by the action of the main current.

All these lamps suffer from the same defect—they are only applicable for isolated cases; they do not lend themselves to the most indispensable requirement of lighting, to the distribution of light. The reason why is not very far to seek, and has already been given in the chapter on Arc Lamp Installations (p. 91.)

The practical solution of the difficulty has been achieved, as already mentioned on p. 91, by placing the regulating apparatus in a shunt of the main current, and thus securing the independency of each lamp in a circuit.

We distinguish two classes of lamps founded on this principle:—

A. *Shunt lamps.*—The current in these lamps is divided into two branches, of which one passes from one terminal through the two carbons to the other lamp terminal, whilst the other branch leads to an electro-magnet, and thence to the second lamp terminal. The current action is in these lamps always opposed by the mechanical effect of a weight or a spring (weight of the upper carbon, etc.).

B. *Differential lamps.*—Both the approach and the withdrawal of the carbons is here effected by electrical action. Two solenoids, one wound with stout, the other with fine wire, establish the necessary balance of the carbons, and no mechanical effect comes into play.

§ 4. POLYPHOTAL LAMPS.

A. *Shunt Lamps.*

1. *Serrin Lontin's Arc Lamp.*

This lamp, too, is an instance of an original model, that of Serrin, being improved by recent alterations carried out by Lontin. Fig. 47 shows the arc lamp now in use. The carbons are superposed as in Foucault-Duboscq's lamp, the position of the two carbon-holders h h_1, as well as that of the upper (positive) carbon on the left, and of the lower (negative) carbon h_1 on the right, is merely indicated in the sketch. Carbon-holder h actuates by natural gravity the large wheel r, which gears in with the rackwork of the holder, while h_1 is hollow, for the reception of the movable special holder h_2 of the lower carbon. On the axis of wheel r is a disc s, with one end of a chain fastened to it, while the other end of the chain is fixed to the support t of the lower carbon-holder h_2.

By pressure of the upper carbon-holder on wheel r the chain is wound up, and raises the lower carbon, while the upper carbon sinks down. The diameters of the wheel and of the chain disc are of such dimensions that the two carbons are displaced according to their waste.

The clock-train ends in the lower ratchet-wheel r_1, and its movement is controlled by the electro-magnet *e*, which acts on the movable oblong check *a b c d*, to which is attached the armature *a*. The check *a b c d* is kept in equilibrium by two spiral springs, and a rail *b d* connects it by means of a transverse piece fastened to support *t*, with the lower carbon; this rail carries a detent *z*, which can gear in with the lower fly-wheel r^1, for the arrest of the clock-train. By means of screws, one of the two spiral springs is so adjusted as to give to the regulating apparatus the required degree of sensitiveness, and so far to lift check *a b c d* that detent *z* is released. In this case the clock-train is set in motion; the two carbons touch, and in consequence of the pressure exercised thereby, the oblong check is slightly lowered, and the detent *z* stops the clock-train.

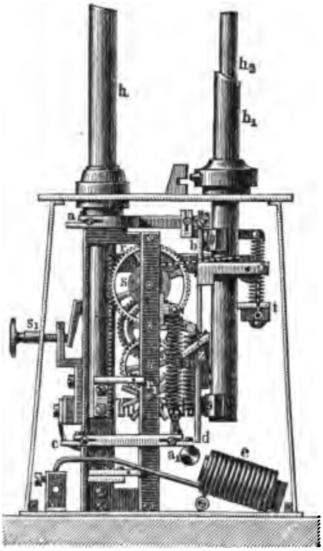

Fig. 47.

The positive current enters through carbon-holder *h*, passes through both carbons, and, from the insulated lower carbon, through the windings of the electro-magnet to the negative pole of the dynamo. The passing current causes the attraction of armature *a*, a consequent lowering of check *a b c d*, and of the lower carbon. The arc is hereby formed, while the movement of the clock-train remains suspended.

By the waste of carbons, or the respective lengthening of the arc, the attractive action of the electro-magnet is diminished, the spiral springs raise the oblong check, and with it the lower carbon, until the detent *z* is released from the ratchet-wheel, and the clock-train is again set in motion for the approach of the carbons. As soon as the attractive action of the electro-magnet, in consequence of the decrease of resistance of the arc, preponderates anew, the clock-train is again arrested.

Both the Foucault-Duboscq and also the Serrin lamps, especially the latter, have been in extensive use; but the tendency has been of late to revert to types of simpler construction. They have been mentioned in this place because they undoubtedly formed the starting point for many of our more recent types of arc lamps.

2. *Bürgin's Lamp.*

It has been shown on p. 175 how Bürgin has modified his original type so as to convert it into a shunt lamp.

3. *Crompton's Lamp* (*v.* p. 177) has undergone the same process.

4. *Fontaine's Lamp.*

In this lamp, as in nearly all other electric lamps, the positive is the upper carbon, and joined to the upper carbon-holder; the direction of the current is indicated by dotted lines (Fig. 48.) The apparatus has three electro-magnets E_1 E_2 E_3, with resistances increasing in the order named. Of these E lies in the shortest circuit, E_2 and E_3 in shunts of this circuit; the shunt passing through E_2 leads to the carbon points and feeds the arc. Armature a of E_1 is in

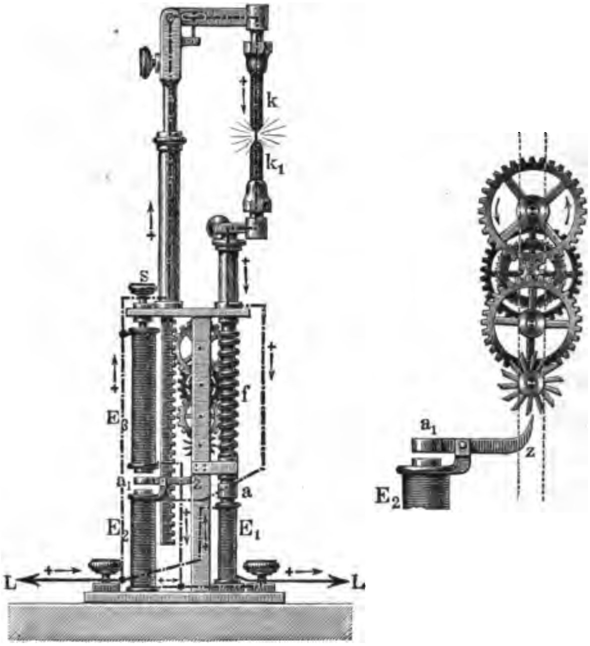

Fig. 48.

solid connection with the lower carbon-holder, and is by a powerful spring f kept apart from the core of the electro-magnet. E_2 and E_3 have a common armature a_1. This latter carries at its extremity a detent z, which, on being attracted by E_2, gears in with a small brake-wheel (lowest wheel) and arrests its motion. The motion of a wheel-train is hereby stopped, which had been set going by the gravity of the upper carbon-holder terminating in a rack-work and gearing in with the wheel-train.

In a state of rest the two carbons are in contact. When the current passes, armature *a* is attracted by E_1, and with it the lower carbon-holder for the formation of the arc; whilst by simultaneous attraction of the common armature a_1 by E_2 the motion of the clock-train is arrested. Through the waste of the carbons the arc is lengthened, its resistance increases and weakens the current circulating through E_2, whilst at the same time the shunt current in E_3 is strengthened to such a degree that the attraction of a_1 takes place in that direction. The wheel-train is thereby released and allows the descent of the upper carbon until the arc is of normal length, when the attractive force of E_2 will again preponderate. The current passing through E_1 is not sufficiently weakened by the variations of resistance of the arc as to release its armature *a*. This only happens in the case of a complete interruption of current, so that *a* during working always preserves a fixed position, as long as spring *f* is stretched sufficiently tight. The regulation of the lamp is effected entirely and solely by screw S, which can raise and lower the electro-magnet E_2.

This lamp, together with those of Jaspar, Lontin and Crompton, presents the advantage of allowing, within certain limits, a variation of current strength without interfering with the regular working of the apparatus.

5. *Gramme's Lamp.*

Fig. 49 shows the latest construction of this lamp. The upper carbon *k* is cylindrical, the lower k_1, for the purposes of more perfect downward radiation, is square.

Both carbon-holders are movable; *h* presents the form of a rackwork gearing in with the wheel *r* of a simple wheel-train; this train is at a normal length of arc arrested by a detent *z* stopping the little brake-wheel r_2. The frame-work of the lower carbon-holder *h* is joined at the top by a transverse bar of soft iron *a*, which is under the influence of the electro-magnet *e*; two rods for the guidance of the armature protrude from the cores of the electro-magnet.

The motion of the upper carbon-holder is, by the aid of the wheel-train, controlled by a second horse-shoe shaped electro-magnet, whose armature a_1, with the movable lever h_2, raises and lowers the detent *z* by the co-operation of spiral spring *f*, and thus arrests and releases the wheel-train according to requirements. During

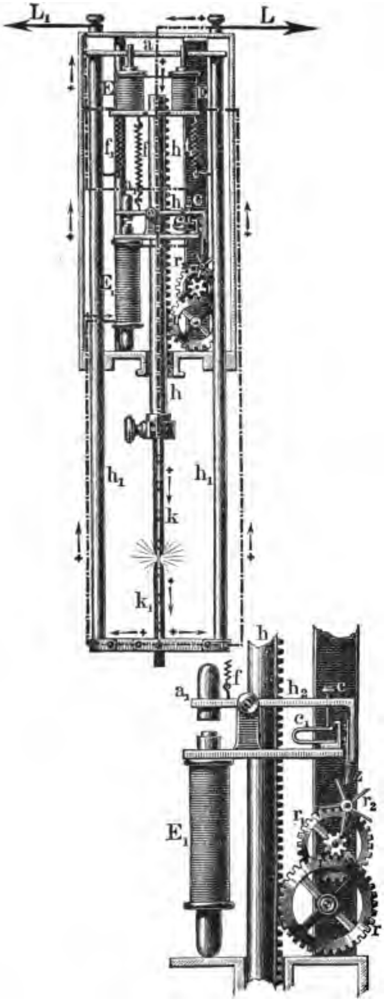

Fig. 49.

the motion of armature *a* or lever h_2, there occurs in the circuit of electro-magnet E an alternate making and breaking of contact between the screw and the contact-spring C^1, and this intermittent and at the same time automatic effect is considered specially favourable for the regulation of the carbons.

The current entering at L flows through the upper carbon-holder *h*, the carbons *k* and k_1, the lower carbon-holder h_1 (on the right), the windings of the electro-magnet E and back to L_1, or the second pole of the dynamo. From this main-current branches off a shunt starting from the carbon-holder h_1 (on the left), and passing through the windings of the electro-magnet E_1, over contact-spring C_1, and contact-screw C on to L_1, provided this contact is closed. When the current passes while the carbons are in contact, armature *a* is attracted by electro-magnet E_1, and the lower carbon-holder h_1 descends for the formation of the arc. In this position the armature *a* remains as long as the circuit is closed. As soon as it is broken, for instance by the extinction of the light, armature *a* is pulled back through the intervention of the spiral springs *f f*, and the two carbons re-enter into contact. The shunt current passing through the windings of electro-magnet E is (the arc being normal), on account of their high resistance, not powerful enough to attract the armature a_1, so that the contact c/c_1 remains closed by the action of spiral spring *f*. But as soon as, in consequence of waste of the carbons, a lengthening of the arc occurs, and the resistance of the main circuit is thereby increased, the shunt current is strengthened in such a measure that an attraction of armature *a* is the result. And now contact c/c_1 is broken, whilst at the same time detent *z* of the armature lever h_2 recedes from the brake-wheel r_2; the wheel-train is hereby released and lowers the upper carbon. This motion, however, is arrested again after a very short time, because the open contact c/c_1 interrupts the shunt current, whereby the armature *a* is released and the wheel-train arrested; this re-establishes the contact c/c_1, so that the regulation can proceed in the same manner. It is clear that this method for regulating the arc offers great advantages and ensures a nearly uniform length of arc. Five of these lamps in one circuit are stated to give 1,100 candles each at an expenditure of 6 horse-power. The lamp is not unfrequently used in France and in Spain.

6. *Weston's Lamp.*

The lamp is represented in perspective in Fig. 50. Fig. 51 shows the details of the mechanism contained in the upper box. The tube at the top of the box contains the rod *k k*, which carries the upper carbon. When no current circulates in the lamp, this rod descends by its own weight, and the two carbon points are in contact. When the lamp is started, the rod *k* can be arrested by a curved lever *h h*, which raises an armature *a a*, attracted by the electro-magnet *e e*; this armature, being fastened to the two horizontal springs *f f*, can only move up or down. The electro-magnet is of special construction; it is wound alternately with coarse and fine wire, but the two wires are wound in inverse sense, so that the action of the electro-magnet depends on the differential action of the currents which traverse these wires. There is a spring at S whose tension can be regulated by a screw acting on an articulated lever.

The movement of the armature, therefore, depends on the difference between the tension of this spring and the attractive force of the electro-magnet. The lamp acts as follows:—The carbons being first in contact, the current arrives through the terminal at the left (Fig. 50), traverses the coarse wire of the electro-magnet, then the carbons, and ascends on the right of the lamp-frame to the terminal on the right. The electro-magnet, now being energized, lifts its armature, which carries with it the lever *h h* and the rod *k k*, and the arc is established. The fine wire of the electro-magnet is likewise connected to the terminals of the lamp, and constitutes therefore a shunt of the main current. The strength of the current circulating through this shunt will increase in proportion to the distance between the carbons, and consequently the resistance of the arc. As soon as this resistance increases, the current traversing the fine wire coils is strengthened, the intensity of the magnet is lessened, the armature is lowered, the carbons draw

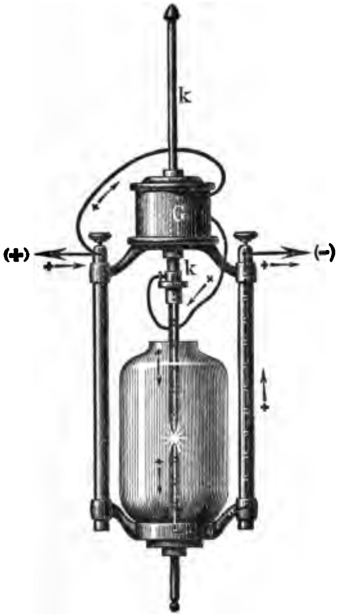

FIG. 50.

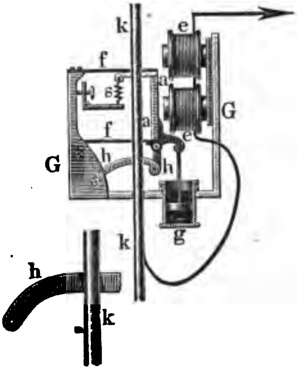

FIG. 51.

nearer to each other, and the shunt current becomes weaker. If from some cause or other the arc is extinguished, the armature is entirely released, the two carbons touch anew, and the current is re-established.

To damp down the movements of the armature, it is connected to the rod of a piston, which moves in a cylinder filled with glycerine. This piston is formed of two discs *g*, each of which has three triangular notches on its circumference; one disc is fixed on the rod of the piston, the other capable of rotating round it. The notches can be made to coincide with or to pass by one another, and the movement of the piston is thus regulated with great nicety.

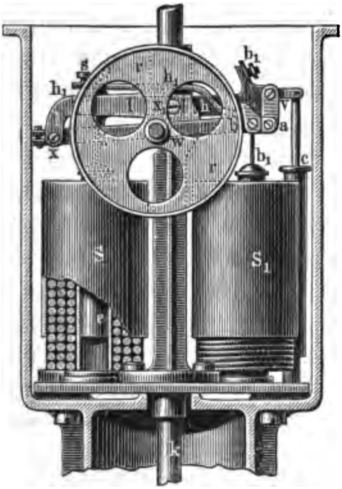

Fig. 52

Weston has also constructed a double carbon lamp, on the same principle as the one described in the preceding lines. We need not enter here into further particulars concerning it, especially as the original lamp has since undergone considerable alterations and improvements.

Fig. 52 shows the latest type of the Weston lamp. The lower carbon is fixed, the upper *k* is movable. The latter is suspended to a cord which passes over a pulley on whose shaft a brake-wheel *r* is likewise fastened. On the wheel acts a brake b_1, which can arrest the motion originated by the gravity of the upper carbon.

The brake is fastened to the extremity of an arm *a*, movable about x_1, the latter being actuated by the articulated lever *h*, movable about x_1, with the assistance of the connecting piece *r*. Flexible strips *b*, attached to the lever *h*, carry the movable iron cores *e* of the coils S S_1, and thus the movement of these cores is transmitted to brake *b*, which is adjustable by screw *s*; connection is made between the screw and the brake by means of lever h_1. To damp down the movement of the carbons lever *h* is connected to the rod of a perforated piston which moves in a cylinder C filled with glycerine. The low-resistance coil S is in the main circuit, while coil S_1 of high resistance is placed in a shunt.

When no current circulates, the two carbons are in contact; the current on entering raises brake *b*, imparting to the brake-wheel a retrogressive motion favourable for the formation of the arc. When the resistance of the arc increases through waste of the carbons, the current is strengthened in coil S_1, its iron core is thereby attracted, the brake is released, and the upper carbon descends, until by the strengthening of the current in S the brake gears in anew and arrests the motion.

In case of an accidental extinction, the current in S_1 being likewise strengthened, the upper carbon descends until it touches the lower one, and the arc is formed in the same way.

The lamp is provided with a sensitive electro-magnet of very low resistance, whose armature recedes on extinction of the light and short-circuits the lamp, so that the working of the other lamps in the same circuit is not interfered with. For a larger number of lamps in circuit this purpose is attained by the current regulator mentioned on p. 100. The results obtained with this lamp have been in the highest degree satisfactory. Comparative tests made at Paris in 1881 gave the following results:—

For one H.P. expended:

	Candles obtained.
Weston system (10 lamps in circuit)	587
Gramme „ (5 „ „)	574
Brush „ (40 „ „)	469
„ „ (16 „ „)	409
„ „ (38 „ „)	399

The arc in these lamps of 1·5 ohms resistance is not quite 1 mm. long, and the light is extremely steady and perfectly white.

The United States Electric Lighting Co., which works the Weston system, has three central stations in New York, besides a special station for the lighting of the Brooklyn Suspension Bridge. These three stations, with an expenditure of 1,950 horse-power, feed 2,100 incandescent and 1,975 arc lamps.

The Brooklyn Suspension Bridge is lighted by 70 arc lamps, arranged in two circuits of 35 lamps each in such a way that two successive lamps belong to alternate circuits, thus securing the bridge against complete darkness in case of an accident to one of the dynamos. The length of the two circuits is about 4 miles, and each circuit is fed by two 20-light dynamos connected in series and driven by a special engine. This dynamo requires 14 horse-power running at a speed of 900 revolutions per minute, and gives 650 volts and 25 ampères. The dynamos, engines, etc., are placed at the Brooklyn Station, but in order to guard against any interruptions arising from disturbances at the Brooklyn Station, the leads on the New York side of the river are connected to the circuit of the large Weston Central Station in New York, so that in case of necessity the bridge can be lighted from the station. A number of local companies using the Weston system are successfully working central stations, supplying a large number of lights at Boston, Springfield, Providence, Rhode Island, etc.*

7. *Brush's Lamp.*

The great simplicity of the Brush lamp consists in the fact that the feed is actuated by gravity alone, while it is controlled solely by the influence of a magnetic field upon a bar of iron; the intensity of the field varies with the strength of the electric current passing through the lamp circuit. In all the lamps the lower carbons are fixed, and, as they burn away, the upper carbons follow them, so that the arc gradually descends; but for special installations, such as lighthouses, or for purposes of projection, a focus-keeping arrangement has to be applied.

Like most of the modern electric lamps, the upper carbon descends by its own weight until it touches the lower carbon, and the circuit is thereby completed; the effect of this in the lamp we are describing is to cause the soft iron plunger to be drawn upwards to a more or less extent within a solenoid, or sucking magnet, and, through the intervention of a lever and an annular clutch surrounding the rod of the upper carbon like a washer, the upper carbon is lifted away, and the arc is established. As the carbons burn away, the arc has a tendency to become longer, and its resistance to increase; and this, by diminishing the current strength, diminishes the supporting power of the magnetic helix, allowing its plunger to descend, and, in so doing, to lower the carbon and shorten the arc until the proper strength of the current is restored, when the rising of the plunger once more holds the carbon in position. To ensure the individual independence of each lamp and a uniform light, each of the bobbins of the controlling magnet is wound with two distinct coils of wire—the first consisting of a number of turns of thick wire through which the main current is transmitted to the arc, and the second of a much larger number of convolutions of fine wire which forms a shunt circuit between the terminals of the lamp, the connections being made in such a way that the current shall pass through it in a direction opposite to that in the thick-wire circuit. This forms a shunt circuit of high resistance, which, being always closed, is independent of the arc. It will readily be understood that, as the current flows in the opposite direction around the magnet, the influence of the fine-wire circuit will be to neutralize or weaken the attractive influence of the thicker helix; but the number of convolutions of the two coils, as well as their respective resistance, are so proportioned to one another that the attractive influence of the thick helix (when the arc is of its normal length) shall overcome the influence of the shunt circuit. Owing to the greater resistance of the latter, not more than one per cent. of the main current is transmitted by the fine-wire helix, but its magnetic influence is rendered considerable by the greater number of convolutions.

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* *Vide* 'Electric Lighting in America,' by W. H. Preece: *Journal of the Society of Arts*, Dec. 1, 1884, p. 67.

From the above description it is clear that, since the electric current has two routes from one terminal of the lamp to the other—the one through the arc, and the other independent of it—should the arc become too long, its resistance will increase, and a large proportion of the current will be shunted through the fine-wire helix, while the strength in that of the thicker helix will diminish, the resultant magnetic influence on the plunger will be reduced, and the upper carbon will descend closer to the lower; on the other hand, if the arc becomes shorter than its normal length, its resistance is reduced, more current flows through the primary helix, and less through the secondary, and the carbons are drawn further apart.

Fig. 53 is a diagrammatic sketch, showing the course of the primary circuit, and illustrating the general principle by which the arc is controlled; it also shows the short circuiting contrivance by which any accident to one lamp,

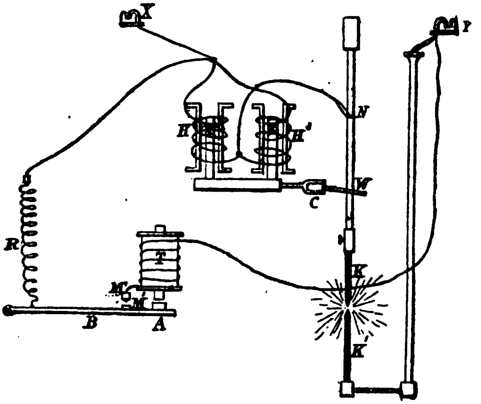

Fig. 53.

or irregularity of working, cuts it out of the general circuit, and does so without exercising any influence upon the other lamps in the series. In this diagram X and Y represent the two terminals of the lamp, which in most cases consist of hooks which, by being dropped over pins attached to the ceiling and which are connected to the line circuit, place the lamp in circuit with the machine. The current, entering at X, is transmitted through two hollow bobbins H H^1 in parallel circuit, the outcoming ends being joined together and connected to the upper carbon-holder N, and if the carbons are in contact, the current flows through them and by the vertical rods of the lamp to the terminal hook Y. The effect of this is to connect the solenoids H and H^1 into magnets, which, by drawing into themselves the two iron plungers N and S, lift one edge of the washer clutch W; which, by its oblique action, seizes the carbon rod (much in the same way as the tent-rope tightener grasps his cord), and lifts the upper carbon till its influence is balanced by that of a fine-wire helix, which, it must be remembered, surrounds the thicker coil.

The short-circuiting apparatus, shown to the left of the carbons K and K^1 (Fig. 53), consists of an electro-magnet T, wound with a thick- and fine-wire coil, similar to those of the regulating solenoids, but both wound in the same direction. When the thick-wire circuit of this magnet is complete, it forms a shunt of less resistance between the terminals, and therefore short-circuits the lamp, transmitting the current of the main circuit. Now the fine wire wound upon this magnet is in circuit with the fine wire of the regulating solenoids; it follows, therefore, that if—through a failure of the arc, or through it becoming abnormally long, or through any considerable increase in its resistance—a larger proportion of current be diverted through the fine-wire circuit, the attractive force of the electro-magnet T would be increased, and its armature A, which is attached to the pivoted lever B, would be attracted, the contact pieces M and M_1 would thereby be brought together, and the terminals would be short-circuited through the thick coil M and the resistance spring R. By thus short-circuiting the terminals through a route altogether independent of either the fine- or the thick-wire solenoids, their magnetic action ceases, and either the upper carbon is dropped, or, if it is burned, or from any other cause the arc is not established, the contact pieces M and M_1 are held firmly together by the attraction of the magnet T, and the current flows past the faulty lamp to others in the series, its extinction calling attention to it, while the other lamps become proportionately brighter. The carbon-pencils are one foot long, and are electroplated with a thin covering of copper; they last about 8 hours, during which time about 9½ inches of the positive and about 4 inches of the negative carbons are consumed.. When, however, the lamps are required to burn for a long period, double-carbon lamps are employed, fitted with two pairs of carbon-holders (Fig. 54); and each is controlled in the same way as in the single-carbon lamp, but the controlling apparatus is not duplicated. When the lamp is put into action, the arc is formed between two pairs of carbons, and when they have burnt out, the other pair automatically starts into action and continues to burn until it is in turn consumed; in that way the time of

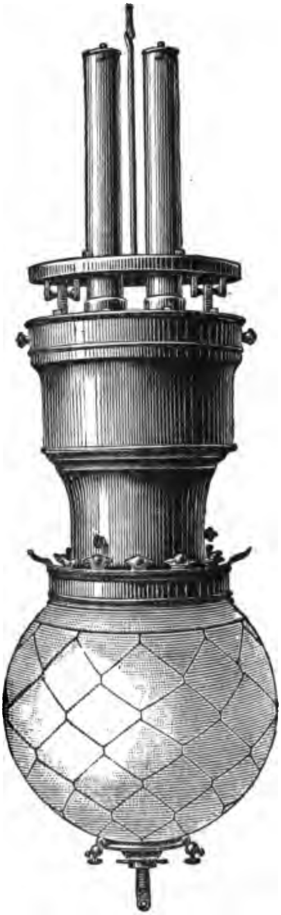

FIG. 54.

burning is doubled, and in order to extend the period of burning, it is only necessary to employ a lamp with a third pair of carbons, when it will be capable of illuminating for 24 hours, each additional pair of carbons extending the period of burning for another 8 hours.

The change from one pair of carbons to the new pair is effected by purely mechanical means, and by a contrivance as ingenious as it is simple. This little apparatus will be understood by reference to Fig. 55. R^1 and R^2 are the carbon rods which pass vertically through the casing of the lamps, and W^1 and W^2 are the clutch washers which surround them. One side of each of these washers passes between a pair of jaws, forming part of the little frame K, and when the latter is drawn upwards its action is first to lift the washers and to cause them to clutch the rod on diagonally opposite corners. By the very simple device of making one pair of jaws a little higher than the other, it takes its grip before the other begins to act, and consequently lifts its corresponding carbon higher than its neighbour; the consequence is that only one arc is established, viz., across the lesser distance, and in all consequent feeding and controlling the pair of carbons first

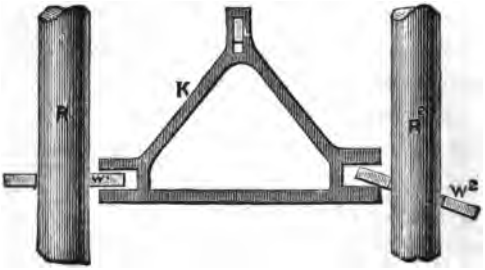

FIG. 55.

stated are alone affected, because, although raised and lowered together, the lower end of the reserved carbon is always higher than the other by the difference in the heights of two pairs of jaws in frame K. A time arrives, however, when, owing to the shortening of the consuming carbons, they can no longer meet when the frame drops, and the current by which they are again separated can only be transmitted by the reserved carbons coming into contact; the circuit is thereby completed, the new carbons are separated, and the arc between them continues to be controlled by the magnet and clutch in the same way as the first arc was.

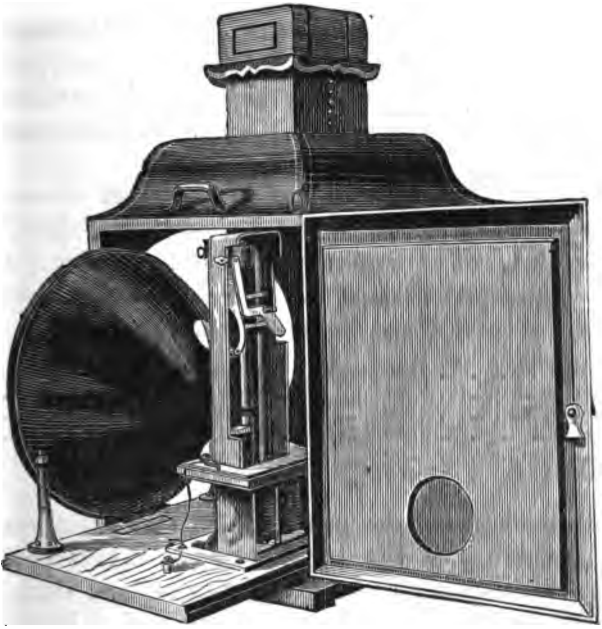

FIG. 56.

Fig. 56 shows an automatic focussing lamp with reflector. The joint resistance of the lamp and arc is stated to be 4·5 ohms, that of the fine-wire shunt-windings of the differential coils 450 ohms. Only 1 per cent. of the total current would according to this be absorbed in the shunt, and as the resistance of the coarse-wire windings of the carbon-holders and carbons together is only ·131 ohms, or 2·91 per cent. of the resistance of the burning lamp, only 3·91 per cent. of the total current energy would be wasted in the lamp, and the whole remainder of 96·09 per cent. would be expended in the arc. The lamp current given at 10 ampères.

The Brush Company is one of the most successful electric-light companies in the United States; how important it is will be seen from the fact that it has 25,000 lamps burning every night all over the States. To mention a few of its central stations only; it has at—

New York	**1800 lamps.**	**Baltimore**	**600 lamps.**
Philadelphia	**1000 „**	**Buffalo**	**550 „**
Rochester, N.Y.	**1300 „**	**New Orleans**	**600 „**
Boston	**600 „**	**Detroit**	**550 „**
Albany	**500 „**	**San Francisco**	**400 „**
Cincinnati	**400 „**	**Cleveland**	**300 „**

At the central station in Philadelphia the larger portion of the motive power is supplied by two Corliss engines of 250 horse-power each; in addition to these there are eight Porter-Allen high-speed engines, each driving one dynamo. Each dynamo is provided with a regulator, described on p. 98.

The lamps fed by this central station are divided into 22 circuits of 50 to 53, and, in some cases, of 60 lamps each.

One of the circuits is 12 miles long; the longest distance of one individual lamp from the central station is 4 miles.

8. *Lever's Lamp.*

In most lamps it is usual to have an electro-magnet, or solenoid, in circuit with the carbon points, to separate them, thus forming the arc; and also a shunt electro-magnet, or solenoid, to regulate the arc in each lamp, when several lamps are worked on a single circuit. This is true of the Brush, Weston, and other well-known systems. One of the advantages of the Lever lamp is that it dispenses altogether with one of these magnets, one technically called the "main," and is regulated solely by the shunt magnet or solenoid.

In this lamp the upper carbon-holder traverses a metal roller which is opposed to the armature of a vertical electro-magnet. The armature is in a state of rest, kept apart from the cores of the electro-magnet by means of a spiral spring. The metal roller is in this position tilted sideways and clamps the upper carbon-holder. As soon as a sufficiently strong current circulates through the windings of the electro-magnet the armature is attracted by the cores, the metal roller assumes a horizontal position and the carbon-holder slides down till the carbons come into contact. The electro-magnet is in a shunt of the main current which passes through the carbons; consequently, as soon as the current passes through the carbons, the electro-magnet becomes inert, releases its armature, the carbon-holder is lifted up, and the arc is formed.

Through the waste of the carbons the shunt current is again strengthened, the armature is attracted afresh and the upper carbon slides down, thus preserving the proper length of the arc.

A modification of this arrangement is represented in

Fig. 57, where in the place of the metal roller the spring levers, *h h*, are employed, which are fastened to the armature *a* of the electro-magnet E E, and clamp the upper carbon-holder when the armature recedes, whilst they allow it to slide down as soon as the armature is attracted.

In both constructions, the carbons being apart from one another, the current would at the commencement of working circulate through the electro-magnet windings of all the lamps connected in series, and would there meet with such a high resistance that it would not be sufficiently developed for the working of the dynamo. To overcome this difficulty, Lever uses an electro-magnetic switch which acts in the following way:—

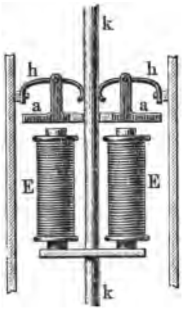

Fig. 57.

Connected to the terminals, or binding screws, of the dynamo are the ends of two coils of wire, which are wound over the limbs of a horse-shoe electro-magnet to a metal stud fixed on a board, which, by means of a spring contact-piece moving through an armature capable of rotating a short distance opposite to the poles of the electro-magnet on a pivot, allows the dynamo to excite itself through the coils of the electro-magnet. Now, when the dynamo has excited itself and is ready to supply the current, the electro-magnet, becoming magnetized, attracts the armature, causing the contact-pieces to leave the metal stud, and thus to break the circuit formed by the coils. Immediately this takes place, the current goes through the shunt electro-magnet on the lamps, that is, when there are a number in series or single circuit, and causes them to form their arc as already explained. With a Bürgin dynamo, which, when running at full speed, gave an E.M.F. of 190 volts, Lever worked 4 lamps of 2,000 candles each at the Crystal Palace Exhibition, in 1882.

9. *Gérard's Lamp.*

This is another lamp of very simple construction worked by alternating currents. It consists of a hollow electro-magnet *e* allowing a free passage for the upper carbon *h*. This electro-magnet, with a fine wire, is mounted in a shunt on the terminals of the lamp. An articulated brake, with a screw, keeps the upper carbon in position, the pressure of the brake against the carbon being regulated by a spring. The upper part of the brake carries an armature, and when this armature is attracted, the brake frees the carbon and allows it to descend.

The lower carbon is supported by a movable vertical frame h_1 h_1 carrying an armature at its upper end, and the armature is placed at the lower extremity of the electro-magnet. The movable frame is balanced by two spiral springs, which are to be seen on the right and left of the electro-magnet. When at rest the carbons do not touch.

The apparatus works in the following way: When the current enters the lamp, the carbons are apart from one another; the current can therefore only pass through the fine wire. The electro-magnet consequently becomes very powerful, and attracts both the upper and lower armatures. The upper armature, acting on the brake, frees the upper carbon, and allows it to descend. The lower armature raises the frame and the lower carbon. As soon as the two carbons are in contact, the current passes into the main circuit; and that which passes into the shunt is sensibly weakened. The lower armature is released, the lower carbon descends, and the arc is established. On the other hand, the armature of the brake is partly released, and the screw presses against the upper carbon, and prevents it from descending. If the screw is properly adjusted, balance is made; but in proportion as the carbons are consumed, the arc will be lengthened, and the strength of the current in the electro-magnet will increase. The brake is now gradually loosened, the alternating currents will produce an oscillation of the armature, and the upper carbon slides down imperceptibly and continuously to maintain the requisite distance.

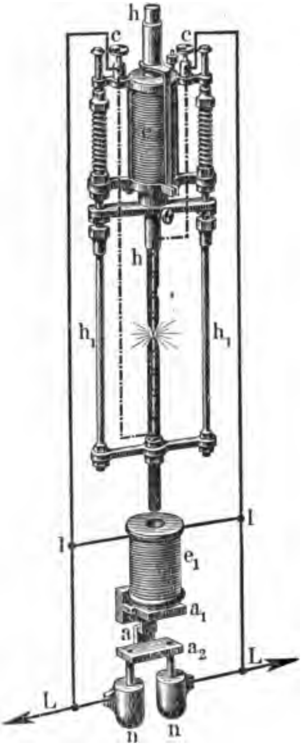

Fig. 58.

In order to prevent any disturbance in the working of a number of lamps in one circuit, Gérard has constructed an automatic cutout for short-circuiting any individual lamp which may have been extinguished. It consists of a small wooden block, to which an electro-magnet e_1 with fine wire is fixed; this electro-magnet is connected to the upper terminals *c c*, which themselves are connected to the lamp; it is therefore in a shunt. The two lower terminals L L communicate with two beakers *n n*, half full of mercury; the left-hand terminal is connected to the arrival wire, and the right-hand terminal to the return wire of the current.

Underneath the straight electro-magnet is an armature a_1 carrying a small hook a, to which, by means of a second hook, a crossbar a_2 is suspended; this latter supports two iron rods placed immediately above the beakers. When the current passes into the lamp, the electro-magnet, which is mounted in a shunt, does not receive sufficient current strength to attract its armature. When the current—as for instance, in the case of an accident—no longer traverses the lamp, the electro-magnet becomes powerful enough to attract its armature, frees the hook, and causes the iron rods to fall into the mercury; a direct communication is established, and the lamp is short-circuited without interfering with the general circuit.

This apparatus, as simple as it is ingenious, works in the most perfect manner. The two beakers can be placed one above the other, the principle remains the same, but less room is taken up, and the apparatus can be placed on the narrow pillars of workshops and factories, for which Gérard's lamp and cutout seem to be specially adapted.

10. *Mersanne's Lamp.*

This lamp has been constructed with the view of obtaining a light for at least 16 hours, by using very long carbons; only part of this length, however, is actually in the circuit, so as not to increase the resistance. Clockwork is used for the movement of the carbons.

When the arc tends to lengthen itself, a larger part of the current passes into an electro-magnet placed in a shunt; the armature sets free the clock-train, which causes an approach of the carbons, until the resistance of the arc has gone back to its normal value.

The necessary retrogressive movement for the formation of the arc is obtained by a second electro-magnet placed in the circuit of the shunt, which only acts when the whole current passes into this shunt, either by the breaking of the arc or because the arc is not formed. At the moment when the current enters the apparatus, the whole current passes into the electro-magnet placed in the shunt; the first sets free the mechanism for the advance, the second attracts its armature and pushes forward one of the carbons.

When the two carbons are in contact, the electro-magnets of the shunt become almost inactive, as the greater part of the current passes through the arc, and they release their armatures; the armature of the first electro-magnet arrests the advance of the carbons, that of the second produces withdrawal by the action of an opposing spring. Mersanne's lamp is used, with a Lontin machine, for lighting the goods station of the Paris, Lyons and Mediterranean Railway at Paris. A single machine feeds 18 lamps in six circuits of three lamps each. In spite of the complication of the movements of the clock-train and multiplying wheels, the lamp gives very satisfactory results.

11. *Thomson-Houston's Lamp.*

In this lamp the regulation of the carbons is effected by an alternate clamping and release of the upper carbon-holder. The mechanism closely resembles that of the Brush lamp, with this difference, that in place of the two superposed coils with alternate coarse- and fine-wire windings, two pairs of coils are used, of which the two upper ones are wound with fine, the two lower ones with thick wire. The regulation of the arc is, as in the Brush lamp, entirely due to the action of gravity on one hand, and to the differential effect of the two pairs of coils on the other; the pair wound with fine wire being, as in Hefner-Alteneck's lamp, placed in a shunt, while the coarse-wire coils are traversed by the main current. The iron cores of the coils have a conical shape, as first used in the Pilsen lamp, and are attached to a common articulated lever movable about a horizontal axis, which according to its motion in one sense or the other unclamps the carbon-holder, and thus causes the upper carbon to descend.

Each lamp is provided with an automatic cutout, which in case of extinction short-circuits the lamp, and thus prevents it from interfering with the other lamps in the same circuit.

The lamps have an average resistance of 4·5 ohms,* and an E.M.F. of 45 volts. A 25-lamp circuit absorbs 23·25 H.P.

In 1884 the Thomson-Houston Company had over 5,000 lamps burning in the United States. In most cases the lamps are simply connected in series, but Thomson has devised an arrangement by which several series can be joined for quantity. For this purpose he introduces in each series a powerful electro-magnet wound with coarse wire and having a coil of large dimensions. He showed at the Philadelphia Exhibition an example of this system in which a current of 9·6 ampères was divided into two branches of 4·8 ampères, each constituted by a series of arc lamps.

The Thomson dynamo (25 lighter) has an electromotive force of 1,200 volts and a current of 9·8 ampères; and in his installations, Thomson places glow lamps on his arc circuit in as many shunts as there are incandescent lamps. In case of breakage, the lamps are provided with a safety apparatus composed of a number of resistances and electro-magnets, which, by means of two commutators, can be either singly or jointly introduced into the lamp circuit.

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* *Vide* W. H. Preece, *Journal of the Society of Arts*, Dec. 5, 1884, p. 68.

12. *The Zipernousky Lamp.*

This lamp, which is manufactured by Messrs. Ganz & Co. of Budapest, is intended for alternating currents, but can, by a simple exchange of coils, be used with continuous currents as well.

The lamp (Fig. 59) consists of a metal plate A, carrying two rods B which are joined by a transverse piece. To the latter is fixed the lower carbon, whilst the rods are by asbestos and hardened india-rubber insulated from the plate.

On the upper side of A and in electrical connection with it are two rails C, and an oblong check D E F G is pivoted about its lateral enlargements. The frames E E are joined together by the rods F. The rails C carry a coil G which is wound with a large number of convolutions of fine wire.

One end of the wire is connected to C, the other by means of screw *a* to the terminal K. A hollow metal tube D forms the core of the coil G, and in it moves a piston fastened to a rail which is opposed to upper extremity of the tube. The core is in movable connection with frame E E of the oblong check.

At F are the axles of the toothed wheels 1, 2, 3, and of the brake-wheel 4, which can be arrested by the lever C; a screw *m*, fastened to rail C, regulates the lever. A rack-work *b*, which carries the upper carbon, and has guidance in two transverse pieces *d*, gears in with wheel 1. Two small electro-magnets H are opposed by the armature I, which is screwed on to the oblong check. The windings of these electro-magnets are connected on the one hand to the screw *a*, and on the other to the insulated metallic contact *e* above which the contact spring *f* is screwed on to F.

When no current passes the oblong check, by the action of the weight of the core, is tilted up, so that the spring *f* does not touch the contact piece. The spiral *g*, which can be regulated by the screw *h*, opposes the weight of core D.

The current enters the upper carbon through C, and passes through the flexible piece *i* into the oblong check and thence through the sliding contacts *k k* into the rackwork.

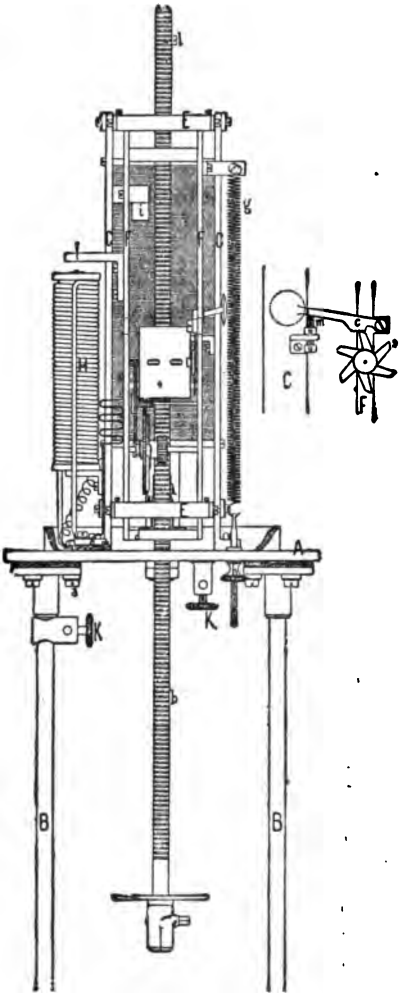

FIG. 59.

If now the current enters the lamp through terminal K, the carbons being apart from each other and the check being lifted up, it must take its way through the shunt coil G. The core is sucked in by the coil and the other side of the check is lowered, and with it the rackwork and the upper carbon. As soon as the carbons touch, the current passes through them and the coil G becomes nearly inert. The action of the piston, however, prevents a sudden lowering of the core, and a withdrawal of the carbons to the requisite distance for the formation of arc ensues.

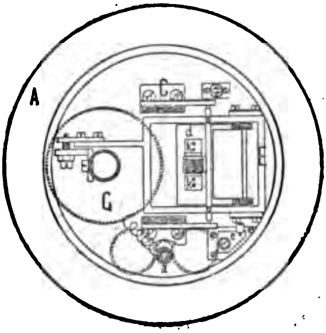

Fig. 60.

As soon as the arc is formed, the resistance of the circuit is increased; more current again passes into the shunt coil, and the iron coil assumes a position of equilibrium within it.

In proportion as the carbons are consumed, the current in the shunt increases, the core of the shunt coil is raised, and the upper carbon descends. This descent continues until the lever *c* releases the brake-wheel 5, and with it the clock-train 1, 2, 3. The rackwork thereby descends as well, and by its weight turns the wheels until the arc is of normal length. At the same time the current in the shunt is weakened, the core is lowered, tilts up the front side of the oblong check, and the brake-wheel is again arrested by the lever.

It will be seen that the regulation is effected by the weight of the core, and this weight can be increased or diminished by tightening or loosening the spring *g*.

If now the carbons are so far consumed that the screw *l* touches the upper guiding piece of the rackwork, no further forward feeding of the carbons is possible. The length of the arc increases, and the lamp is ultimately extinguished. The whole of the current would now pass into the shunt. In order to prevent this, the following simple contrivance has been made:—

Through the action of the current on core D this latter ascends, and the contact spring *f* descends with the oblong check until it touches the piece *e*. The current now passes from the oblong check through *e* and *f*, and the windings of the electro-magnet H; these latter attract the

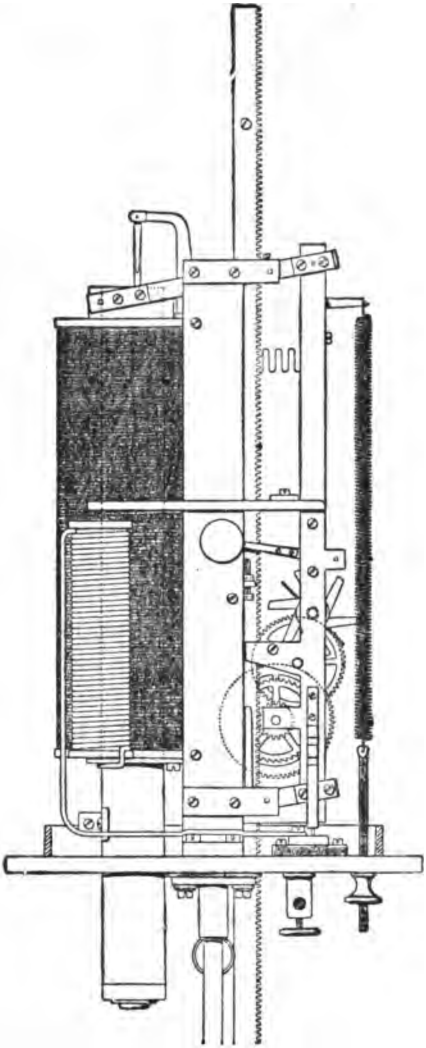

FIG. 61.

armature I, and thus keep *f* pressing against the contact *e*. The action of these magnets is so intense that it overbalances the effect which the windings of G have upon D —that is to say, the armature I cannot recede.

Fresh carbons are now inserted, and the upper carbon holder sinks lower, until the carbons touch. The current is now divided, and only a small portion of it flows through the coils H. The armature I is less strongly attracted, and recedes from the magnet through the action of the weight of core D. The carbons withdraw from one another, and the arc is formed.

The lamp shown in Fig. 59 is intended for 8 burning hours, whilst Fig. 61 represents a double-carbon lamp, of the same construction, capable of burning 16 hours.

The lamps vary from 600 to 4,000 candles.

Fifteen lamps of 1,000 candles each were fed by one of Messrs. Ganz' continuous current machines giving 62 volts and 120 ampères at 1,100 revolutions per minute.

The alternating machine of the same firm, giving 62 volts and 452 ampères at 625 revolutions per minute, feeds from 20 to 30 lamps of 800 candles each.

The amp is one of the most extensively used in Austria, Hungary, and Italy; more than 120 installations with over 1,000 lamps have been made within the last three years.

B. DIFFERENTIAL LAMPS.

1. *Siemens' Differential Lamp.*

The principle of this lamp, invented by Hefner von Alteneck, has already been fully described on p. 92 and following pages, and it only remains for us now to give the details of construction of the apparatus, showing once more in Fig. 62 a diagrammatic sketch of the current path through the lamp, which first solved the problem of division of electric light, as far as arc lamps are concerned.

The lamp represented in Fig. 63 has two coils E E_1 and a movable lever a_1 connecting the iron rod e with the upper carbon-holder. The upper carbon-holder consists of a rack z with a clip a for the reception of the carbon. The rack z is not directly connected to the lever a_1, but a guiding frame A A is pivoted to the lever at a_1, and by a short parallel motion bar a_2 at the bottom is free to move vertically only. The rack z acts on the pinion and ratchet-wheel r_1, the rotatory motion of which is governed by the escapement bar e_1 (Fig. 64) fixed to the pendulum p. This latter is arrested in its oscillation by a small bar a_3 fixed to the frame a_1 that is coupled to the solenoid. The pendulum rod is extended upwards beyond its pinion; and this enlargement when raised by the upward movement of guiding frame A A, gears into a notch of the crossbar a_3, and thus arrests the rack z by means of the escapement e_1; when the guiding frame descends, the crossbar a_3, is lifted up by a fixed pin at s, the escapement is thus free to act, and the carbon-holder descends. When the current circulates, the carbons being apart from each other, there is only one path for it, namely, through coil E_1. This latter attracts the iron rod e, frame A A descends, rack z becomes free and descends with the upper carbon. This descent, which is naturally slow, since rack z actuates the ratchet r and with it the escapement e_1 and pendulum p,

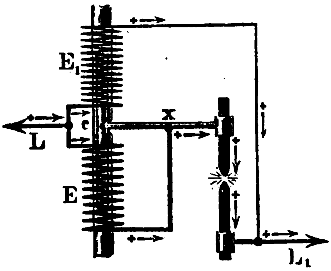

FIG. 62.

is continued until the upper carbon is in contact with the lower fixed one. At the moment of contact the greater portion of the current passes through coil E, which on account of its low resistance is most powerfully energized, sucks in the iron core e_1 thereby raising frame A A and with it the upper carbon, and the arc is established. The resistance of the arc weakens the current in E and strengthens that in E_1 until the two effects being neutralized, the iron core is kept in a position of equilibrium. By a proper adjustment of the mechanism this position of equilibrium is arranged in such a manner that crossbar a_3 lies close to its release pin *s*, so that even the slightest variation of current strength consequent upon the consumption of the carbons alternately arrests and releases the rack *z*. In this way the requisite length of arc is constantly maintained.

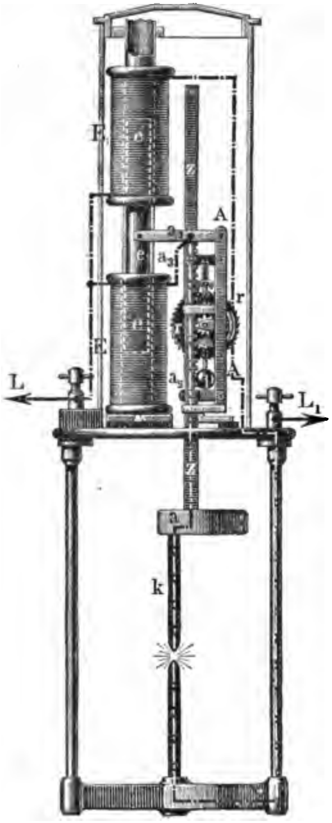

FIG. 63.

Even if by some cause or other the current strength in the circuit L L varies, the ratio of current strength in the coils E and E_1, and consequently the positions of equilibrium are not affected by these variations, although the intensity of light must naturally show the effects of these variations; the adjustment of the system is effected by raising or lowering the upper solenoid E_1 by means of a screw. No variations of light can be traced through the rapid changes of current (about 120 times per second) in a Siemens alternating machine. There can be no doubt that the automatic regulation of the length of the arc within comparatively wide limits, and independent of the strength of the main current, the two principal results obtained by employment of the differential lamp, constitute advantages of the highest order and affording much greater elasticity in the arrangement of lamps in different circuits. On the other hand, it is an indisputable fact,—a fact to which we have repeatedly referred in the preceding pages—that alternating machines are inferior to continuous current machines for arc lighting, and, on carefully considering the pros and cons of the question, we can only say that the use of alternating currents, except in cases of necessity,—as, for instance, with the Jablochkoff candles,—remains a moot point to be decided only by the individual requirements of the installation.

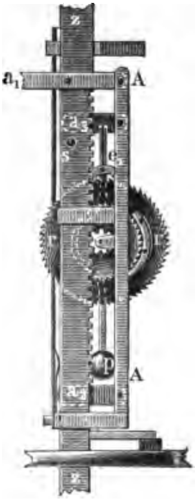

Fig. 64.

Fig. 65.

Fig. 65 shows the lamp complete in its usual form. The mechanism is enclosed in a copper or brass cylinder, and the arc is protected by a globe of opal glass which is surrounded by a net of fine wire. From four to seven of these lamps are generally placed in one circuit; two or more circuits are fed by one alternating machine, the lamps giving about 250 candles each. One horse-power is calculated for each lamp; the illuminated area in the case of a railway station being 500 square metres per lamp.

We refer the reader to p. 91 for further particulars on the practical use of the differential lamp.

2. *Piette and Krizik's* (*Pilsen*) *Lamp.*

This lamp deserves attention especially because in it the two magnetic attractions arising from the same source regulate the light without any further mechanism, and without application of any other forces than those due to the current itself.

An extreme simplicity of construction has been obtained by this method, and the mechanical resistance and other deleterious obstacles have been reduced to a minimum. This result has been obtained in the following manner:—The current, before entering the lamp, is divided into two parts, each of which traverses one of two superposed solenoids, in which an iron rod of peculiar shape slides up and down. The principal current traverses the first solenoid constructed of coarse wire, whilst the shunted current traverses a solenoid composed of a large number of very fine wire spirals. The relation between the resistance in the solenoid and the number of spirals has been calculated in such a manner that, as soon as the arc attains a fixed and determined resistance, the iron rod remains in equilibrium under the influence of the two solenoids. When the resistance increases, the equilibrium is broken, and an adjustment takes place. The carbon could therefore be fixed directly to the rod, if the attraction of the solenoids for each position of the rod remained the same. But this is not the case. When an iron rod penetrates into a solenoid traversed by a current, the attraction is a maximum when the end of the rod is at the same level as the medium line of the solenoid. When the rod advances beyond that line the attraction gradually decreases, and is equal to zero when the middle of the rod coincides with the middle of the solenoid.

This is the reason why a lamp constructed on the above principle would not act well, for the adjustment could only be effected for very short distances. Piette and Krizik have overcome this obstacle by giving to the rod a peculiar conical shape.

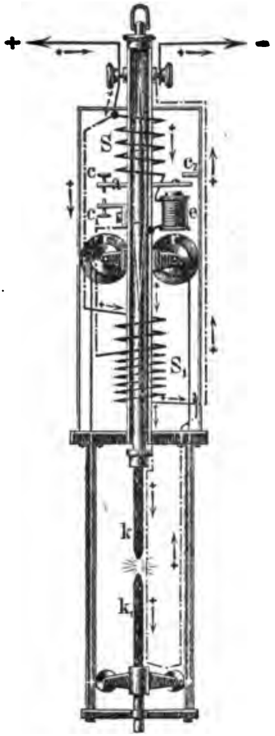

FIG. 66.

Under these conditions the attractive power of the solenoid remains the same almost for one half of the rod, for different diameters of this rod correspond to differences in the attractive power of the solenoid. A regular motion of the rod in the solenoid for a considerable distance can be obtained in this way, and the carbon can be fixed directly to the rod without the intervention of an intermediate mechanism.

In Fig. 66 the conic rod moving inside the two solenoids S S_1 carries a metal tube to which is fitted the upper carbon, while it is connected with the lower carbon-holder by means of two strings passing over the two pulleys *r r*. The upper and lower carbon-holders thus act in an opposite way on the motion of the conical rod, but being in a position of equilibrium, the current circulating through the solenoids is alone able to move the rod. Solenoid S consists of coarse wire, and has a low resistance, while solenoid S_1, on the other hand, is formed of a larger number of fine wire spirals.

As will be seen from the sketch, the positive current passes through solenoid S, through the coils of a small electro-magnet *e* (whose function we will consider later on), the upper carbon-holder, the arc, through the lamp-case, and the lower carbon-holder, to the negative pole of the dynamo or the next lamp in circuit respectively. But the positive current, on entering the lamp, branches off, and the shunted current passes through solenoid S_1, and thence directly to the metallic lamp-case.

No movement takes place as long as the arc is of normal length, but as soon as its length increases through consumption of the carbons, the current in solenoid S is strengthened, sucks in the iron rod, and thereby causes the upper carbon to descend, whilst at the same time, by the action of the two strings joined to the conical rod, the lower carbon with its holder is raised. Both carbons simultaneously moving in opposite directions, the arc is maintained at the same height.

If the light is extinguished while the current circulates, the latter would, as long as the carbons are not in contact, only find *one* open path through solenoid S; it would therefore meet with a considerable resistance within the extinguished lamp, and thus interfere with the light of the other lamps in the same circuit, unless the danger was averted by some special arrangement. This consists in the employment of an electro-magnet *e*, with three contacts $c\ c_1\ c_2$, of which *c* is connected with the electro-magnet itself, c_1 with solenoid S_1, at the place where the coarse and fine wire spirals meet, whilst c_2 is fixed to the lamp case. If the current circulates through solenoid S and the spirals of the electro-magnet *e*, armature *a* is attracted, and there is no connection between the contacts (*v.* Fig. 66). But if the current is broken in S and *e* by extinction of the arc, the armature goes back to its original position, making contact between the contacts c/c_1 and closing the contact c_2. The fine wire windings of solenoid S_1 are hereby short-circuited; the current required to bring about the approach of the carbons passes through the coarse-wire spirals of solenoid S, and if their resistance is so arranged that it does not deviate to any considerable extent from the resistance of the arc, no disturbing influence will manifest itself in the remaining lamps of the circuit.

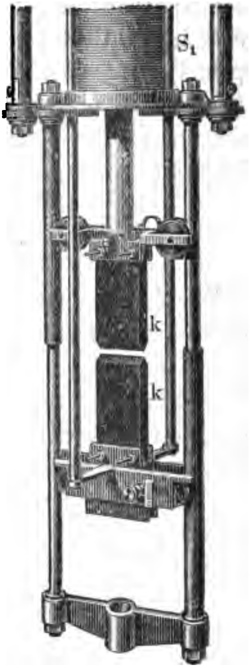

FIG. 67.

The Pilsen lamp can be readily adapted to any fittings or application for lighting. Fig. 67 shows a factory lamp with plate carbons, intended to burn 100 hours. The electrical connections are the same as those in the lamp shown in Fig. 67. The small control electro-magnet is fitted in the top wooden frame at the right side, and is then out of the way of harm. The mechanical construction of the lamp is much stronger than that of the hanging lamp; there are two sets of contact rollers—one set attached to the top and one set to the bottom carbon. The principal novelty in this lamp is the use of plate carbons *k k* in the place of the usual cylinders. This was the feature of the Wallace lamp introduced in America in 1878 and shown in London in the same year.

3. *Tchikoleff's Lamp.*

The latest model of this lamp shows an entirely different construction from any of the lamps described in the preceding pages. It consists mainly of a Gramme ring placed between two diametrically opposed electro-magnets; one of these, with coarse wire, is traversed by the main current, and the other, with fine wire, by a shunted current; the ring can turn in either sense, according to the predominating influence of either of the two electro-magnets. This double movement of rotation can be utilized to produce the withdrawal or approach of the carbons, with this advantage, that the movements are the more rapid the further the apparatus is from its position of equilibrium. Tchikoleff's apparatus are arranged for continuous currents. They possess the advantage of acting without any clockwork, springs, or electric contacts, no previous adjustment is required either before or during the time of action, and the light remains constant in spite of any possible variations of current strength. The lamp is used by the Russian

Artillery, and it is claimed that 20 to 24 Bunsen cells give a very good light.

Edison and Schuckert have also constructed lamps on a similar principle, employing a small electromotor for the regulation of the carbons. These lamps, however, have never found any extensive application in practice, and we therefore refrain from giving details concerning them.

C. ARC LAMPS OF SPECIAL CONSTRUCTION.

1. *Gülcher's Lamp.*

The lamp, which employs neither shunted currents nor differential coils, is represented in Fig. 69, and, as will be seen, is of very simple construction.

The two carbon-holders h h_1 are connected by means of a cord passing over two pulleys r r_1, in such a manner that the one holder follows the movements of the other. The upper holder h is of soft iron, and moves before the rounded pole of a straight electro-magnet e, which is free to oscillate about x upon the trunnions of a metal ring. The position of the electro-magnet is controlled by an adjustable spring f, under whose influence it rests against the stop a, while its second pole, extended downwards, is opposed by a small iron block b attached to the case of the lamp.

As soon as the whole or part of the working current circulates through the electro-magnet coils, the upper carbon-holder h is attracted to the rounded pole, and at the same time the extended part of the second pole is attracted by block b, thereby causing the electro-magnet to turn on the trunnions of the ring. By this movement the carbon-holder h is necessarily lifted; the two carbons k k_1 are thus separated, and the voltaic arc is established. As the carbons burn away, and the distance between them becomes greater, the resistance increases, and consequently the power of the electro-magnet diminishes, it begins to turn

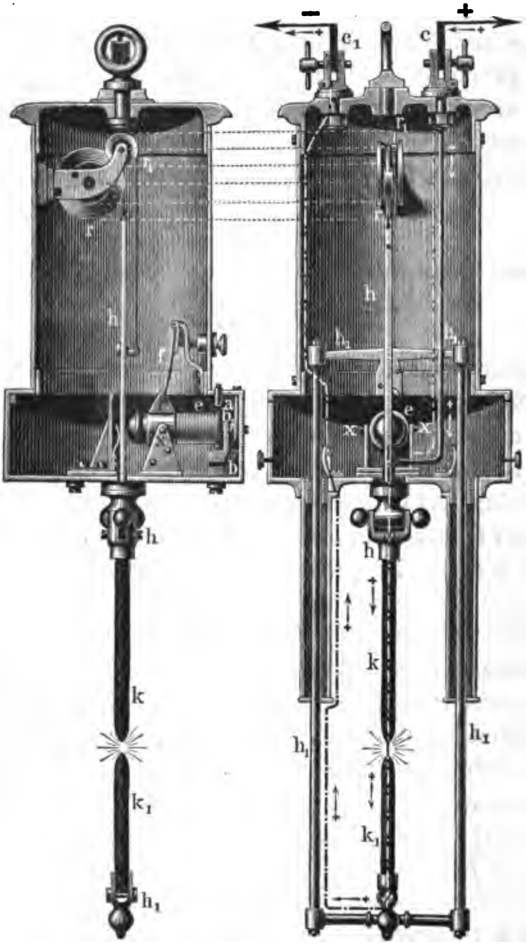

FIG. 68.

under the now preponderating influence of spring *f*, until it is arrested by the stop *a*. As soon as this condition has been established, the magnet has no further movement, the carbons continue to burn until they are at that distance apart corresponding to the greatest intensity of light. As soon however as further consumption increases the distance, the attractive power of magnet *e* becomes too small to enable its armature to hold the bar *h* carrying the upper carbon, and the bar begins to slide down until the carbons are brought nearer together, and the power of the magnet is increased so that it again holds the bar *h* and prevents it slipping further. An accidental breaking of current brings the carbons into direct contact, whereby the same process is repeated. The small iron block b_1 attached to spring, acts as a brake and damps down the action of the electro-magnet when the lamp is started, and secures a soft and easy movement.

Such is the arrangement of the Gülcher lamp. It now remains to be seen how the peculiarities of its arrangement render it suitable for being used in groups in the same circuit, and how one lamp acts as the regulator of the second, the first and second as the regulator of the third, and so on. This regulating action depends on the positive motion of the electro-magnet, and upon the quantity of electricity flowing through the circuit. To take, first, the simple case of two lamps put in parallel circuit with the generator. If a lamp A be first lighted by connecting the branch wire from the terminus of the electro-magnet to the main conductor from the positive pole of the dynamo, the light will establish itself, as has been already described; then, if the connection with lamp B be completed, the current is divided, and lamp B is lighted. At first the part of the current flowing through lamp B is stronger than that passing through lamp A, because the carbon points of the former are in contact, and the resistance is less. The result of this inequality is that the electro-magnet of lamp B is set in motion, the carbons are separated, and the resistance is increased; at the same time that this takes place, the current passing through lamp A is strengthened, and the carbons are brought somewhat closer together. From this it will be seen that, if in either lamp the carbons become too far separated, the preponderance of current in the other will tend, through the action of the magnet, to raise its carbon-holder, increase the distance between the points, and so weaken the current in the first-named lamp; then the magnet will cease to maintain the carbon-holder, which will slide down till equilibrium is established or the same process is revived, and so on, one lamp regulating the other, and consequently itself. With three lamps in parallel circuit, the same processes take place; when all three are lighted, lamp A regulates lamps B and C, B regulates A and C, and C regulates A and B.

With a current of 15 ampères, the lamp gives 1,200 candles measured at an angle of 34 degrees; the motive power consumed was found to be 1·66 horse-power for each lamp of 1,200 candles.

2. *Street and Macquaire's Lamp.*

This is one of the latest types of arc lamps, and of very ingenious construction. It differs in its constructive principle from all other arc lamps, and makes use of alternating currents and the vibratory motion produced by these currents when passing through an electro-magnet opposed by a spring armature. Every time the current passes through maximum the armature is attracted; every

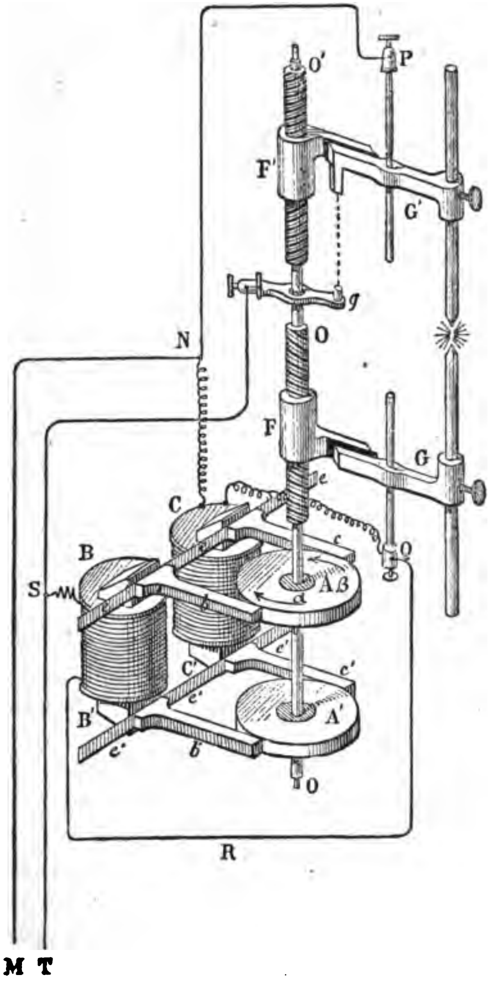

Fig. 69.

time the current is reduced to zero, at the moment of changing its direction, the armature, in obedience to the spring, withdraws. This principle is practically applied to the lamp in the following way: G G^1 (Fig. 69) are the carbon-holders forming the screw nuts of the double screw O O^1; when the screw turns, the two screw nuts and the carbons carried by them approach or withdraw from one another, according to the direction of the movement. On the axis of this double screw is fastened an iron disc A (there are in reality two discs, A and A^1, but as their actions are identical, we will for a moment suppose that there is only one). On either side of the disc are two iron bars *b c*, touching the disc in two diametrically opposite points, and mounted on a small spring plate *e e*. The two extremities of *b* and *c* are opposed by two electro-magnets B B^1, C C^1. Of these, B B^1 is wound with a few convolutions of coarse wire and placed in the light circuit itself, as will be seen from the figure, on following the current path M N P G^1 G Q R B^1 B S T; while C C^1, which has a large number of fine-wire windings, is placed in a shunt between the lamp terminals, as will be seen on following the path M N C C^1 Q R B^1 B S T; this is the arrangement adopted in differential lamps. The action of the lamp is as follows:—The two carbons are in contact at the moment the current enters; the resistance of circuit M P Q S T being very low, the entire current flows through it, and the electro-magnet B B^1 is strongly energized; the contact piece *b*, strongly magnetized, acts most energetically on disc A, and causes it to turn in the direction indicated by the arrow *a*. The screw follows the movement, the two carbons are withdrawn from one another, and the arc is established. At the same time the current is weakened in the electro-magnet B B^1, and strengthened in C C^1, whereby the contact piece *c* adheres more and more strongly to disc A, causing it to turn in the sense indicated by arrow β. For some time there prevails a state of equilibrium, then the distance between the carbons increases through their combustion, electro-magnet C C^1 begins to preponderate, rotation commences in the sense β, and continuing in this direction, compensates for the waste of the carbons, and keeps the current constant; the system a^1 b^1 c^1 placed at the bottom is an exact repetition of *a b c*, and doubles its effect.

The action of the apparatus is most regular and interesting to watch. The small motor *a* a^1 turns with continuous and gentle motion, and the vibrations of the contact pieces *b* and *c* being very rapid, it is not easy to discern the cause of motion. Sometimes, when in consequence of the non-homogeneity of the carbons, the arc has a tendency of abnormally lengthening or shortening itself, the little disc will be seen either to accelerate or to slacken its rotation; sometimes it will altogether stop, or move for a moment in a contrary direction; then, when everything is in order again, it will take up its regular motion. The light, as might be expected, is most steady considering that the mechanism excludes irregularities.

Street and Macquaire have also provided their lamp with an automatic cutout, and an automatic relighting arrangement, upon which we need not enter here.

The installation made with this lamp at the swimming baths of the Rue Rochechouart in Paris works most successfully. Lamps of two different sizes are employed; two self-exciting Gramme machines, type No. 1, supply the current at a speed of 1,400 revolutions per minute. The lamps are arranged in four circuits, of which two and two are identical. The first circuit contains three lamps of larger size in series; these have carbons of 11 mm.

diameter, and give an arc of about 3 mm.; the current is of 10 ampères and 50 volts. The luminous intensity of the naked light at an angle of 45° is given at 600 candles, the opaque globe absorbing about 200 candles. In the second circuit are placed seven smaller lamps in series, in addition to twelve Edison A lamps, which light up some smaller rooms. The smallest type of lamp only requires 6 ampères and 36 volts, its illuminating power with an opaque globe and under an angle of 45° is 200 candles. The carbons have 8 mm. diameter, the waste of both carbons does not exceed 45 mm. per hour. The total number of lamps, as will be seen, is six larger and fourteen smaller ones.

§ 5. GENERAL REMARKS ON THE CONSTRUCTION OF ARC LAMPS.

It has already been mentioned, on p. 144, that a very large number of arc lamps have been constructed in the comparatively short period which has elapsed since the first introduction of electric lighting. We have in the preceding pages endeavoured to give an account chiefly of those lamps which have, either in this country or abroad, found an extensive practical application, and also of some lamps which, either from a historical point of view, or from some peculiarity of constructive details, present features of interest. We have been obliged to omit the description of many lamps of ingenious construction and of reported good efficiency, merely from consideration of economy of space, and because greater stress ought to be laid in a book like the present one on the general results obtained with electric light, and on the best methods for obtaining these results. Amongst the lamps which we have reluctantly passed over, are those of Schuckert, Edison, Million, Mackenzie, Andrews, Naglo, Clark, Mondos, Levett-Müller, Schmidt, Abdank, Haskins, Dornfeld, Cance, Pieper, etc., etc.

This is far from an exhaustive list; new types appear almost daily, and alterations and improvements are constantly being made in the existing lamps. Under these conditions it is not advisable to specially consider the individual parts of the lamps, and we wish to direct the attention of the reader to the following more important general considerations:—

1. The arrangements for adjustment of the carbons at the commencement of working.
2. The connection of the carbons with the leads.
3. The insulation of the circuit within the lamp.
4. The material of the parts of the lamp subject to continuous and quick motion.
5. The duration of the lamp, or length of carbons.

It has been fully explained (*v.* p. 145 and following pages) how important the adjustment of the carbons is for the efficiency of the lamps; of no less importance, however, is the connection of the carbons with the leads, which ought to be of the closest possible kind. Where carbons and carbon-holders have a fixed position, this connection presents no difficulties; but it is different for the movable parts, which have mostly sliding contacts. These are always more or less unsafe, in so far as they not only increase the resistance of the circuit, but are also instrumental in varying, whilst in motion, this resistance within narrower or wider limits. By contriving contacts of non-oxydisable material at or near the points of the carbons, the great advantage is gained of rendering the resistance of the carbons themselves more independent of the continuous shortening through consumption. But even with such an arrangement it is desirable, on account of the inferior conductivity of carbon, that the current should find as many points of contact as possible in the remaining parts of the surface of the carbons.

Special attention has to be paid to the insulation of the circuit within the lamp, so as to prevent any deviation or derivation of current injurious to the formation of the arc. We have in Fig. 63 (Siemens' differential lamp) the insulated parts of the circuit, and have seen that the metallic body of the lamp itself can be utilized as a current conductor. There is no objection to this course if we take care that the metallic connection of the second carbon with the other pole of the generator is not in direct connection with any part of the body of the lamp, and that this latter, if required, has a foundation plate of insulating material. A thorough acquaintance with the conditions of insulation of the circuit is the simplest means for the security of working.

It is clear that the regulation of the lamp must be disturbed by the wear and tear of its movable parts; and as the parts which have the greatest influence on the exact working of the regulating mechanism can easily be distinguished, it follows that they ought to be specially protected by choosing for their construction a sufficiently hard material. Good steel and phosphor-bronze are mostly employed for this purpose.

For purposes of practical illumination it is often of great importance that the lamps should last through protracted periods, so as to simplify the manipulations of maintenance, and to avoid as much as possible the disturbances consequent upon the replacing of consumed carbons. The length of burning hours is dependent on the quality of the carbons and their dimensions. The diameter of the carbons has a certain influence on the emission of light, and can therefore, unlike the length, not be chosen arbitrarily. As regards the latter, we have only to consider in how far the individual construction of the lamp admits of a longer or shorter length of carbons, a consideration of course which has a considerable bearing upon the value of the lamp. The use of long carbons is always accompanied by a considerable pecuniary advantage, because the waste is less, and, the price of carbons being very high, the saving effected is by no means to be overlooked. None of the lamps have an arrangement demanding through an automatic call a renewal immediately before the extinction of the consumed carbons. Such an arrangement seems very desirable, and might perhaps be effected by mixing the carbon with a substance which by its combustion changes the colour of the light.

Schuckert has lately taken out a patent for certain contrivances which automatically bring about contact of the carbons, in case that they are to be exchanged, when burned down to a certain length, before the extinction of light takes place.

One of these contrivances acts in a purely mechanical sense, and by diminishing at the proper moment the counterweight of the upper carbon, causes it to sink down on the lower one without afterwards raising it again. In another construction, a wire coil placed in circuit, and controlling the upper carbon, causes the attraction of an iron core, whereby the contact of the carbons is effected; and in another model this result is obtained by automatic short-circuiting of the windings of the electro-magnet, which, being placed in the main circuit, controls the movements of the carbons for the formation of the arc.

The sensitiveness of the regulating mechanism varies considerably in different lamps. In the same way as every light machine gives the best results for a definite external circuit, so also in a general way does every lamp for a definite mode of connection and a definite current. The construction, however, would be imperfect if it did not allow within certain limits of the adjustment of the regulating apparatus for different current strength. The wider these limits the greater the elasticity, from a practical point of view, of the lamp. An essential condition, however, to be fulfilled by the regulating mechanism is that *when once adjusted for a certain connection* it should not be sensibly affected by the unavoidable variations of current strength. We know that these variations in some cases are very considerable; and it is clear that the requirements of the case arising from this consideration alone are difficult to fulfil. The difficulty increases when two or more lamps are placed in one circuit, and the *variations of current strength manifest themselves simultaneously in all lamps.* This circumstance offers a serious obstacle to the distribution of light, especially as the division itself already weakens the light, and the increase of current strength through an acceleration of speed of the machine is confined to certain limits.

Experience shows that certain lamps are totally unfit for the division of light, and lend themselves for the formation of one single arc only. In every case we have to distinguish between the requirements of one single arc and those of divided light; but even in this latter case the number of lamps in one circuit is not immaterial.

The motion necessary for the regulation is almost exclusively controlled by the working current, partly by employing solenoids, partly by using common electro-magnets. A drawback to this method is that the effects of the currents in the production of motion, and in the formation of light, do not manifest themselves quite uniformly. The magnetizing power of the current, as well as its heating effects, are known; but not so the relation between heat and light; and to this circumstance we may partly ascribe the fact that, if different resistances are employed in the light circuit, the current strength calculated from Ohm's law frequently does not agree with the quantity of light obtained, or, in other words, that the loss of light, on lengthening the leads, is not proportional to the altered resistance.

The current passing through a solenoid has a different effect upon the motion of the regulating mechanism, according to the different position of the iron core of the spiral, so that the attractive action is not uniform in every position. To remedy this defect, the winding of the coil is sometimes not carried out uniformly over the whole length, but arranged according to the magnetizing power at different heights, or the iron core is built up with a gradually enlarged section;* or, as in Jaspar's lamp (*v.* Fig. 38), different weights are employed to counteract the varying magnetizing effects. When using common electro-magnets the distance of the armature from the core greatly influences the sensitiveness; it is not advisable to oppose a *mechanical* counter-effect (spring or weight) to the electrical (respectively magnetic) effect of the current.

It seems advantageous in any case to separate in the same system the coarse-wire from the fine-wire regulation, and this remark applies to single-arc lights, as well as to polyphotal lamps.

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* In the Pilsen lamp the cylindrical core is replaced by a conical rod of soft iron.

The changes within the arc evidently are the main cause of the difficulty encountered in feeding a number of lamps in the same circuit; and, to overcome this difficulty, it is not only the construction of the lamp, but also that of the light machine which has to be considered. Very often what is impracticable with one machine can be effected with another, and we need only refer to the Brush dynamo, which has been successfully employed in maintaining as many as 60 lamps in one circuit, to show how far the improvements have gone in this direction.

An arrangement for ensuring the maintenance of the same length of arc is of course the most favourable for the division of light; and hence it follows that incandescent lighting presents the most rational solution of the problem. On using lamps which require a continual adjustment of the length of arc, the essential condition for successful working is that any, even the slightest, variation in that direction should be *instantly* rectified, that the length of arc in all lamps should always remain uniform. To fulfil this condition, the current requisite for regulation would have to be obtained in *all lamps through a certain given resistance of the individual arcs*, and this would necessitate the working conditions in the entire circuit as well as in all its parts to remain constant. That such conditions cannot be attained, either with regard to electromotive force or to resistance of conductors, etc., is well known; there remained therefore the only expedient, viz., of making the individual lamps in the same circuit independent of one another, to assign to each lamp a special circuit within the main circuit.

It has been previously stated that lamps of varying length of arc, and in which the carbons (or the burning light respectively), and the windings of the regulating electro-magnet or the regulating solenoid, are placed in the main circuit, can with safety be employed only for the production of one single light in the circuit. But even with such a limited sphere of employment, the performances of the different types vary partly in accordance with the conditions of the working of the dynamo, partly with the choice of connections, and finally with the sensitiveness of the regulating mechanism itself.

To consider the construction and effect of electro-magnets and solenoids would lead us too far. The magnetizing power of the electro-magnet coil manifests itself in the attraction of an armature, that of the solenoid in the attraction of a soft-iron core, this attractive force being generally opposed by a mechanical counter-effect, such as the tension of a spring or a counter-weight. The motions caused by these forces can be separated, as for instance in the Crompton lamp (Fig. 44), where the attraction of the armature *a* establishes the arc, whilst the plate in movable connection with the armature maintains the arc in normal length. A similar arrangement we find in the solenoid action of the Brush lamp, where the more or less irregular movement of the iron cylinder separates the carbons, whilst the iron core, moving inside the cylinder, regulates the length of arc. Such combined arrangements (always provided they are properly carried out) are preferable to the simple movement of the armature. In any case, however, we find that a series connection of the regulating mechanism and the arc raises a formidable obstacle to the maintenance of several lamps in the same circuit; for it will easily be seen that, through the greater resistance of the wire coils, the total resistance of the circuit is increased to the detriment of current effect. If we take the resistance of the arc, inclusive of that of the carbons, at 2 ohms, that of the wire coils of the electro-magnet E at 4 ohms, and the resistance of the remaining parts of the entire circuit at 3 ohms, the total resistance of the entire circuit therefore at 9 ohms, we get from Ohm's law a current of $\frac{E}{9}$, which is, within the solid conductor, partly transformed into heat, partly into magnetizing action of the electro-magnet, and is recovered in the production of light.

It is a different matter in lamps where the arc and the magnetizing coil (electro-magnet or solenoid) lie in a shunt of the main current. Here we have, taking again the above figures, resistance r of the light shunt 2 ohms, that of the electro-magnet shunt r_1 4 ohms; whilst the main circuit has a resistance $R = 3$ ohms. We then get the total resistance of the circuit $= R + \frac{r\ r_1}{r + r_1}$; and, according to the laws of shunted currents, we find the current of the light shunt $= \frac{r_1}{r + r_1}$, the current of the electro-magnet shunt $= \frac{r}{r + r_1}$.

In our case the total resistance of the circuit would be $= 3 + \frac{2 + 4}{2 + 4} = 4 \cdot 33$ ohms, the total current $= \frac{1}{4 \cdot 33}$ (assuming an E.M.F. of 1); current of light shunt $= \frac{1}{4 \cdot 33} + \frac{4}{6} = \frac{2}{13}$, and current of electro-magnet shunt $= \frac{1}{4 \cdot 33} + \frac{2}{6} = \frac{1}{13}$.

The total current available at any point of the undivided conductor ($\frac{1}{4\cdot33}$) would, therefore, in the latter case be double that of the former ($\frac{1}{9}$), and the current available for the formation of light would be $\frac{2}{13}$ as against $\frac{1}{9}$, while a weaker current ($\frac{1}{13}$ as against $\frac{1}{9}$) would pass through the coils of the electro-magnet.

The advantages of the second arrangement require no further demonstration, and are the more conspicuous the higher the resistance of the electro-magnet coils. It is true that this resistance, on employing powerful currents, such as are required for electric lighting, is very small compared with that of electro-magnets for telegraphic purposes (these have from 10,000 to 15,000 windings, with a resistance of 600 ohms and more), but we have to consider that the product of the number of windings and the current expresses the magnetizing force of the coil, and that the current for the production of light is several thousand times stronger than telegraphic currents; all these considerations will clearly show the superiority of the second over the first form of construction.

To return, however, to our principal object, namely, to show the advantages of shunt connections for feeding several lamps in the same circuit, we must follow the changes consequent upon the increased resistance of the arc through consumption of the carbons. Let us assume that this resistance has risen from 2 to 4 ohms, the total current would then be

$$\frac{1}{3+\frac{4\times4}{4+4}}=\frac{1}{5},$$ $\frac{4}{8}$ of which belongs to the light shunt and as much to the electro-magnet shunt, i.e. $\frac{1}{10}$. The current in the electro-magnet shunt is thus strengthened through an increase of resistance in the light shunt ($\frac{1}{10}$ as against $\frac{1}{13}$),

and this strengthened current would have to regulate the length of arc, whilst in the former case this function would have to be performed by a weakened current. This, however, does not in itself constitute any special advantage, for it is immaterial whether the requisite motion for the regulation is brought about by a strengthening or weakening of current. But we have further to consider how the results are affected when the alteration of resistance occurs in the *main leads*. Let us assume that at normal length of arc, of 2 ohms resistance, the resistance of the main circuit is increased by 2 ohms, that the total resistance of the latter be therefore 5 ohms instead of 3 ohms, then total current $= \dfrac{1}{5 + \dfrac{2 \times 4}{2 + 4}} = \dfrac{1}{6 \cdot 33}$, $\frac{4}{6}$ of which $= \frac{2}{19}$ belong to the light shunt, and $\frac{2}{6} = \frac{1}{19}$ to the electro-magnet shunt.

In the three cases considered above, we have therefore:

	For the light shunt.	For the electro-magnet shunt.
In the first case . . .	$\frac{2}{13}$	$\frac{1}{13}$
In the second case . .	$\frac{1}{10}$	$\frac{1}{10}$
In the third case . .	$\frac{2}{19}$	$\frac{1}{19}$

We thus find that in the third case, too, an alteration of current strength has occurred in the electro-magnet shunt; the *ratio of current strength*, however, has remained the same in both shunts as in the first case, and this will bear out our assertion that in lamps whose regulating apparatus lies in a shunt the regulation is only dependent on the occurrences within its own special circuit (r, r_1), and is not subject to any disturbing influences arising from variations in the external circuit. This may be to a certain extent admitted; the success, however, in a great measure depends upon special arrangements, especially on the relation of resistance in the two shunts. In practice, however, the matter assumes an entirely different form, in so far as differences of resistance, such as we have assumed in our examples, do not occur in well-constructed lamps. We always take good construction for granted, because with lamps of inferior make satisfactory results cannot be obtained in any case; the more sensitive the apparatus is to slight variations of resistance, the better the result; and the regulation (always assuming a convenient arrangement of shunt resistances) will be most perfect when *either* shunt is provided with an electro-magnet, so that both these electro-magnets can, according *to the difference of the varying current strength*, exert a joint action on an armature, etc. (differential lamps). In such a case changes in the main circuit, which modify the strength of current, have the least influence on the regulating mechanism, because the strength of current in both shunts of the lamp decreases or increases by the same amount (always provided the arc is of normal length), and the combined current action on the *common* armature therefore leaves the equilibrium undisturbed, a necessary requirement to keep the arc of normal length.

From the above remarks on the constructive requirements of an arc lamp it will be easy to form a *general* idea of the practical value of any lamp type, while the decision in any special case requires a knowledge of the relative resistances of the different parts of the lamp circuit. It must here be remarked that the necessary condition for the employment of several lamps in one circuit—the establishment of an individual circuit for each lamp by means of shunts—can everywhere be easily fulfilled. Whether electro-magnets or solenoids are used in any special case is immaterial.

The division of lamps into several groups has only been made for the sake of classification; it must not be thought for one moment that certain characteristic differences are a criterion for the efficiency of a lamp,—that, for instance, a differential lamp must necessarily be of very high efficiency, while a monophotal lamp, a sort of venerable relic, is not worthy of consideration. This is far from being the case; the differential effect is very well in its way, provided that the resistances of the wire coils placed in circuit have a definite ratio to each other, and also that the resistance of the arc be kept constant. But we know that the resistance of the conductors varies with the temperature, and that the resistance of the arc increases with its length, that these relations are therefore constantly shifting. The more powerful the currents employed, the more the wire coils are heated and the higher the temperature of the flames; but while the former thereby suffer a loss in conductivity, the reverse takes place in the flame. The temperature of the latter is also increased by the lengthening of the arc, the greater heat being, according to Joule's law, generated in the higher resistance. To establish the right proportions for the adjustment of these variations is a difficult task, and thus, even supposing the current to be kept constant, differential lamps, too, are subject to certain defects, which may become unpleasantly conspicuous during working, and may interfere with an effective division of light. This aim is by no means secured by the mere fact of shunt connection or of differential action. Simplicity of construction and of motion of the carbons, with sufficient speed to allow of an instantaneous adjustment of any, even the slightest disturbance of equilibrium, are indispensable conditions. Where the mechanism is unable to follow up with sufficient rapidity the variations in the circuit, even the most ingenious constructions must fail; but the sensitiveness of the arc is such that even these rapid motions must be of a uniform nature, a result to be obtained by the employment of properly constructed and delicate brakes.

These mechanical requirements are equally obligatory for monophotal lamps, which therefore deserve our interest in the same measure as the lamps of so-called higher order, quite apart from the fact that it often requires but very slight alteration to provide a monophotal lamp with an arrangement for shunt connection. Under these circumstances it is impossible to arrange the different lamp types according to their real value. The characteristic differences of connection are everywhere easily recognisable, without requiring special grouping, while the other essential requirements are not to be discovered at the first glance, and are often treated as trade secrets.

§ 6. ARC LAMPS WITH OBLIQUE CARBONS.

The first lamp of this kind was constructed in 1846 by William Edward Staite. The two carbons were inserted in two directing sheaths, and descended in proportion to their waste by means of springs, and finally came to abut against a refractory non-conducting substance. The length of the arc is altered by displacing one of the carbons.

1. *Rapieff's Lamp.*

This lamp, invented in 1878, consists of four carbons, two for each pole.

The upper pole is formed of two carbons of a diameter of 6 millimetres, sliding between rollers, which direct their motion and establish a perfect electrical contact. The two carbons form a sort of V, the length of which diminishes with the combustion, whilst its meeting point is fixed. A weight attached to a string causes the carbons to descend; the meeting of the points causes the carbons to stop, and fixes the luminous point.

The lower pole forms a reversed V, lying in a plane perpendicular to that of the carbons of the upper pole. The same arrangement of rollers and strings with weights raises the carbons which, by their meeting, afford a second fixed point as regards their support. This support, which is articulated, is destined to maintain the carbons at a proper distance when the current passes. To obtain this result, a flat electro-magnet with two limbs is contained in the socket; one of these limbs is fixed, and the other articulated at one of its extremities. At the moment when the current passes, the opposite poles attract one another, and the displacement of the lower movable limb of the electro-magnet acts on a rod in one of the vertical supports of the apparatus, and causes a contraction of the support of the lower carbons; a withdrawal of the carbons, which had originally been in contact, ensues, and consequently the formation of the arc. Its length is regulated by a spiral spring opposed to the action of the electro-magnet; a set screw keeps this spring properly adjusted. By this simple arrangement an electric lamp is obtained, in which the luminous point remains fixed, and the carbons are of unlimited length; the resistance, moreover, which these carbons introduce into the circuit is very feeble and independent of the length. In another arrangement Rapieff replaces the two carbons of the upper pole by a single carbon of larger size. In this lamp with three carbons, the part of the electro-magnet is reversed; it only tends to bring the carbons into closer proximity for the purpose of lighting them. When the lamp is lit, this electro-magnet ceases to act; the arc has then a constant length, which is regulated in advance, and only depends on the number of lamps placed in circuit.

Each lamp is supplied with a safety cutout, which short-circuits the lamp, if it should by some cause or other get out of order.

The Rapieff lamps are always used with alternating currents; they allow, to a certain extent, a distribution of light, since four of them can be placed in series in a single circuit.

Similar lamps have been constructed by Killingworth Hedges, and by Gérard; they have, however, not been adopted in practice, and we therefore refrain from entering into details concerning them.

A lamp of very original construction, based on the same principle as the Rapieff lamp, is—

2. *Heinrich's Arc Lamp.*

The latest form of the lamp is shown in Fig. 70; the employment of circular carbons gives to it a very striking appearance. There are two pairs of carbons forming two circles of larger and smaller diameter, the planes of the two circles being perpendicular to one another; in a state of rest the two carbon pairs are in contact at the points where the carbons touch.

The upper positive carbon pair is supported by the arms h h, movable about the points x x; in the same way the carbons k k_1 are supported by the arms h_1 h_1, movable about the axis x_1 x_1. To ensure a uniform descent of the carbons, pinions are placed on the axis at x x and x_1 x_1, which,

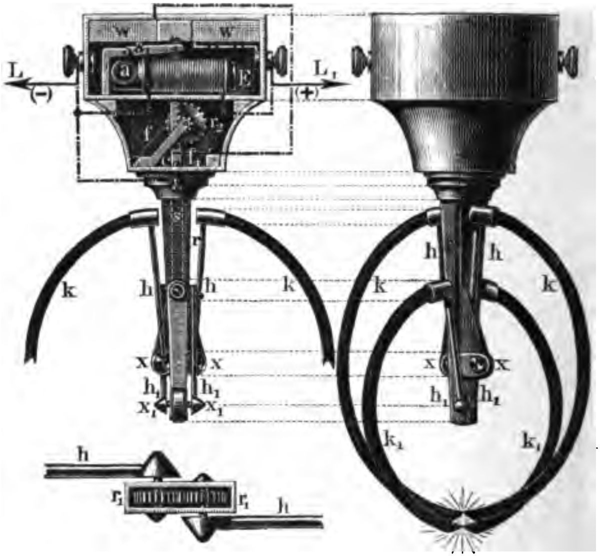

Fig. 70.

by gearing into another, keep the place of contact of the carbons fixed at one point. A rod s carries the geared pivots of the upper carbon pair, as well as the carbons themselves, which are connected to the regulating mechanism placed in the top part of the lamp. The current on entering the lamp passes into an electro-magnet E, forming part of the regulating mechanism, and thence through the carbon pairs in contact to the negative terminal. Electro-magnet E immediately attracts its armature *a*, which is fastened to the shorter arm of lever a_1. This latter is in its turn connected to the rod *s*, which on being lifted brings about a withdrawal of the carbon pairs and consequent establishment of the arc. The movements of rod *s* are damped down by providing it with a number of teeth which gear in with the ratchet of wheel r_2, whilst a spring *f* presses against the circumference of the wheel. This arrangement preserves the distance of the carbon pairs constant, and the feeding of the carbons proceeds in proportion to their consumption under the influence of their own gravity.

If through any accident the lamp should be extinguished the electro-magnet E releases its armature rod *s*, and with it the upper carbon pair sink down until they touch the lower pair, and the arc is established anew. In case of any breaking of current, or after the consumption of the carbon the lamp is automatically short-circuited without interfering with any other lamp of the same circuit. For this purpose a wire coil W W is placed above the electro-magnet, whose resistance corresponds to that of the arc, and is placed in circuit as soon as the arc is extinguished. This effect is obtained by means of a small pin fixed to the rail *s* immediately below the tooth-wheel r_2; when the rod drops the pin presses against spring f_1, and brings it against the contact-screw *c*. The current, as will be seen from the dotted lines of our figure, now passes from L_1, through W W over f_1 *c*, directly to L.

The circular shape of the carbons has the advantage that comparatively long carbons can be employed in a limited space (the Heinrich's lamp burns for 20 hours and more).

A lamp of similar construction is that of Lescuyer.

§ 7. ELECTRIC CANDLES.

An apparatus with a voltaic arc in which the carbons are placed parallel and not end to end is called an electric candle.

In 1846 William Edward Staite invented an apparatus in which the carbons were placed in an oblique position (an intermediate apparatus between the arc lamp and the candles). In 1874 Werdermann patented a sort of electric candle for piercing the rock in mining and tunnelling operations, but which was not intended to produce electric light.

The genuine electric candle, which by a complete absence of any mechanism and its extreme simplicity has gained such notorious success, is due to a Russian officer, Jablochkoff, and dates from 1872.

1. *Jablochkoff's Candle.*

The following is an extract from the patent, which accurately describes this invention :—

"My invention consists in the entire suppression of all mechanism commonly used in electric lamps. Instead of effecting by mechanical contrivances the automatic approach of the carbons in proportion to their combustion, I place these carbons alongside one another, separating them by an insulating substance which is capable of being consumed at the same time as the said carbon—Kaolin, for instance. The two carbons thus prepared can be placed in a special candlestick, and as soon as an electric current from some source or other passes through them, the electric arc is established between the two extremities. For the purpose of lighting, I join the two free extremities by a small ribbon of carbon, which first becomes red hot and serves as a prime of the arc."

The candles, therefore, burn side by side, and are used up in the same time, like the wick of a composite candle.

The insulating substance maintains the arc at the extremity of the candle, and volatilizes in proportion to the combustion of the carbon.

Fig. 71 represents the Jablochkoff in its present form; the two parallel carbons *k k* have a diameter of 4 millimetres and are 22 centimetres long, which ensures for the candles an average duration of one hour and a half. The lower ends of the carbons, which are separated by an insulating substance *g g*, fit into two small brass tubes *h h* of 5 centimetres in length, separated by an insulating substance *m*. Fig. 72 shows a lamp with six candles, the globe being removed. The candles are placed in double clips with springs, and below the bracket (Fig. 73) is a series of connections corresponding with the series of clips. A commutator, placed within reach of the hand and enclosed in a box to screen it from any meddling on the part of the public, turns the current from a nearly wasted candle into a new one. When the lamp contains six candles, seven conductors are sufficient; the first six are each connected with a candle, and the seventh forms the common return wire.

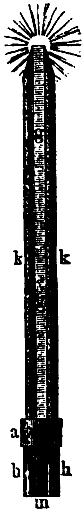

Fig. 71.

A rapid movement of the commutator turns the light from one candle to another, and this momentary interruption of the circuit has no appreciable effect upon the light of the other candles in the same circuit.

The two carbons being insulated, it is indispensable, for the purpose of lighting them, that there should be a previous communication for a few minutes of the points of the candles. At first, Jablochkoff lit his candle directly by placing between the two extremities a piece of charcoal which he removed afterwards when the arc was formed. In order to be able to light from a distance, Jablochkoff has placed between the carbons a piece of graphite fastened by a small ribbon or paper, thus establishing a complete conducting circuit.

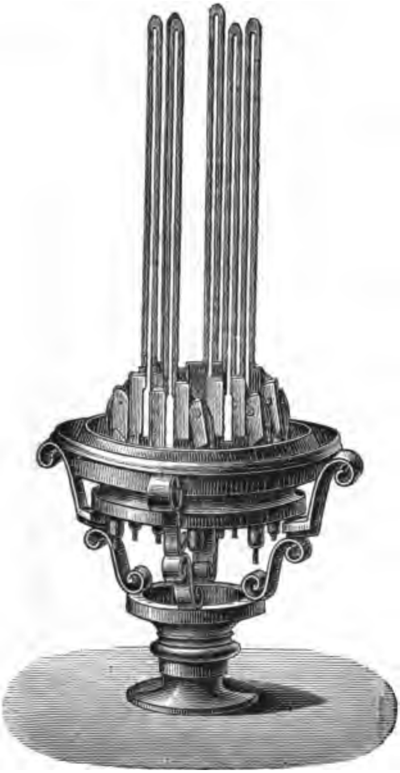

FIG. 72.

When the current is sent into the candle, the little piece of graphite is heated, becomes red hot and is consumed. The arc then appears, and is maintained as long as the candle lasts and the electric current is sufficiently powerful. The graphite can be replaced by a fine metallic wire or a piece of lead.

The Jablochkoff candle has found a great number of applications; direct measurements of the work expended and the illuminating power have repeatedly been made. We quote some of the results of these experiments, presented in May, 1879, to the Metropolitan Board of Works by Messrs. Bazalgette and Keates.

The first installation, which was made on the Victoria

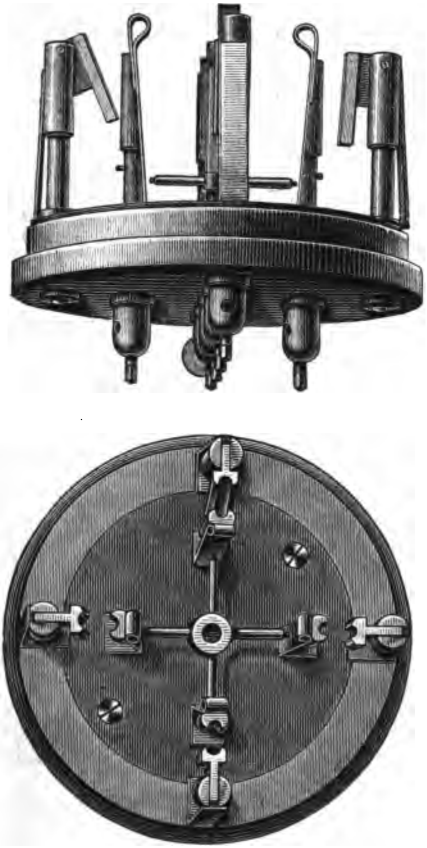

FIG. 73.

Embankment, consisted of 20 candles fed by a Gramme alternating machine arranged in four circuits of 5 candles each.

The work expended by the machine was, deducting work expended by transmission and work in open circuit—

	Total gross work.	Work net.
For 5 candles in 1 circuit . . .	13·57 H.P., or	1·57 H.P. per candle.
„ 10 „ 2 „ . . .	17·91 „	1·27 „
„ 15 „ 3 „ . . .	20·75 „	1·05 „
„ 20 „ 4 „ . . .	23·53 „	0·92 „

The illuminating power was—

For one candle with open light . .	39·8 carcels, or	400 sperm candles.
„ „ frosted globe .	27·3 „	280 „
„ „ opaque globe .	16·3 „	160 „

Opaque globes thus cause a loss of nearly sixty per cent. of the light emitted, and frosted globes nearly thirty per cent.

Of all the systems of electrical lighting the Jablochkoff candle was the first to be extensively used for street lighting; more than 2,500 of these candles were in use in Paris in 1880 and a number of them were to be seen in London. Lately, however, the serious drawbacks of this system, namely, the incessant variations of tint and brilliancy, as well as the noise arising from the use of alternating currents, have seriously checked the development of a system which at the outset seemed to be destined to carry all before it.

Electric candles have also been constructed by Wilde, Rapieff, Siemens and Halske, Debrun and Andrew.

2. *Jamin's Candle.*

Within the space formed by a flat coil composed of about 40 convolutions of insulated wire W (Fig. 74), and covered by a slight casing K, are six carbon rods k_1 k_2 of 5 mm.

thickness, arranged in such a way that the rods k_1 are fixed perpendicularly to the framework attached to the platform p, whilst the rods k_2 are movable by the intervention of a common lever controlled by the armature a of an electro-magnet e; when at rest, rods k_2 touch the rods k_1.

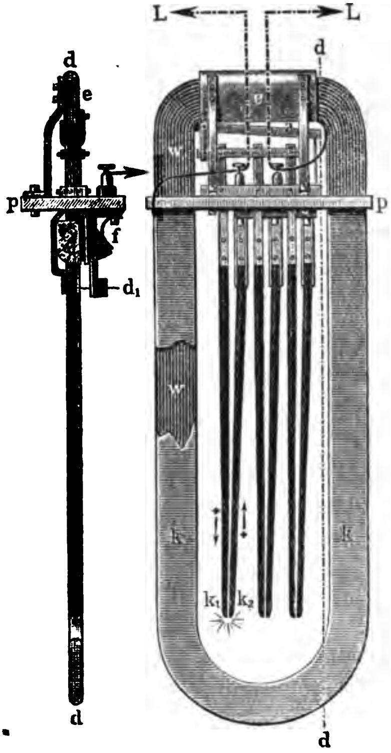

Fig. 74.

The current circulating through the wire coils passes through the pair of carbons destined for action in the direction indicated by the arrows; two currents thus flow nearly parallel to one another in opposite directions. These currents repel each other—an effect which is seconded by the current circulating through the wire coils, and which causes the withdrawal of rod k_2 from k_1 and consequent establishment of the arc. But the arc itself is a movable conductor controlled by the current passing through the coil, and can thus, according to the direction of the passing current, be maintained between the carbon ends, ensuring a steady combustion of carbons in an upward direction.

If, through some cause or other, the current is broken, the carbon rods are, by the release of armature *a*, brought again into contact, and the entering current automatically lights the extinguished candle.

By a simple automatic arrangement, on the consumption of one pair of carbons, a second pair, and after this a third pair, is placed in circuit. The requisite motion is produced by a spring *f*, and commences as soon as the thin brass wire d_1 is melted by the arc in its highest position. The casing K consists of copper foil, platform *p* is of slate. The whole apparatus is suspended to *p*, and enclosed in a glass globe or a lantern. Each pair of carbons burns two hours, and the duration of the whole apparatus is therefore six hours.

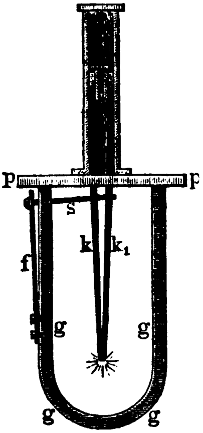

FIG. 75.

A simpler form of candle has been patented by Jamin since, and is shown in Fig. 75. The wire convolutions are contained in a case *g*, which is attached to the platform *p*. An armature plate *f* is opposed to the edge of the case, and carries a pin for the control of the movable carbon k_1. When plate *f* is attracted by the current passing through the wire coils, k_1 is removed from *k* to a distance appropriate for the formation of the arc. The two carbons are in proportion to their consumption lowered by a simple wheel-train. As soon as the light is, through some cause or other, extinguished, the armature plate *f* recedes, and both carbons come into contact, whereby the circuit is closed again and the arc re-established.

3. *The Sun Lamp.*

This apparatus, invented by Clerc and Bureau, forms, so to say, a connecting link between the arc and the glow lamp.

Its construction is shown in Figs. 76 and 77. Two carbons *k k*, slightly deviating from the vertical position, penetrate through a marble block M to the face of a cavity on the lower side of the block. The latter is fastened to the case *g* by means of screws, and the two carbons *k k*, slightly guided by two copper wires *d d*, sink down through inclined cylindrical holes in the block, in proportion to their waste, being prevented from slipping through by the construction of the holes. As in the Jablochkoff candle, the combustion is started by a prime placed between the extremities of the carbons. The current enters the apparatus by the two wires L L connected to *d d*.

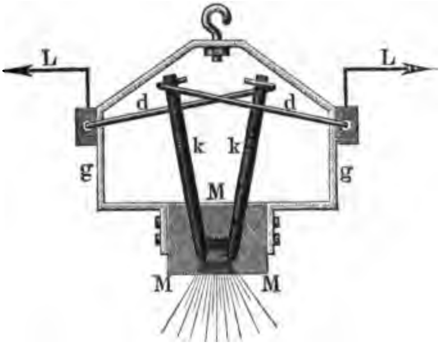

FIG. 76.

When once the arc is established, it is maintained in spite of the great distance between the carbon ends, because the surface of the marble, or the magnesia, between them has had time to become a conductor through being heated during the preparatory period of lighting.

This arc of great length heats the marble and produces an intense light of a yellow tint, to which the lamp owes its name.

The Sun lamp (Fig. 77) throws all its light downwards,

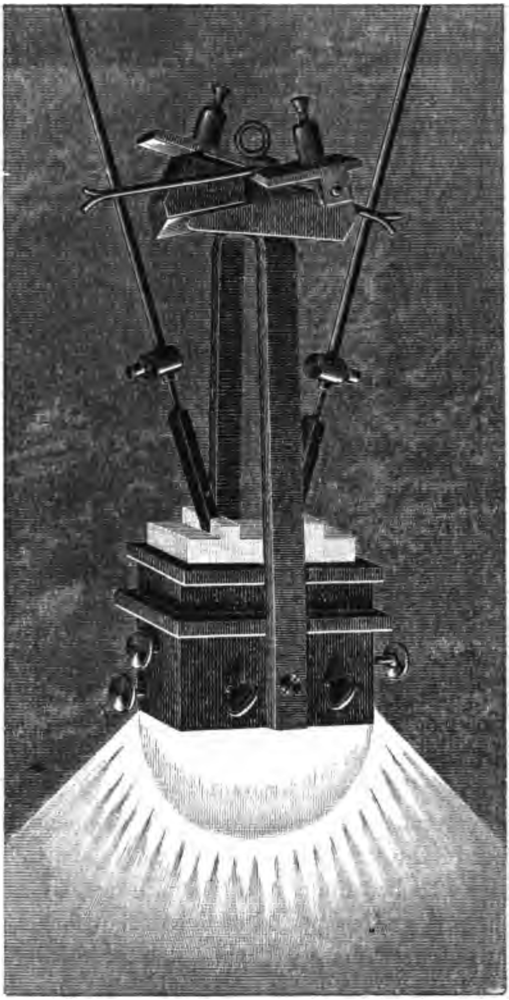

FIG. 77.

which is as a rule desirable; but the total suppression of light in any other direction is sometimes objectionable. Moreover, the different pieces surrounding the luminous part of the marble throw a shade, and assign to the luminous rays a limited area. When the light is to be thrown upwards, to light up the ceiling, for instance, the lamp is simply reversed, and the carbons are fed forwards by the aid of springs. By an ingenious contrivance, however, the springs can be dispensed with, if there movable carbons are placed by carbon blocks of comparatively large size; these blocks are gradually worn out, until the arc becomes too large, and the lamp is extinguished. This arrangement was used for the experiments in lighting the lobby of the Paris Opera.

The lamp is generally worked with alternating machines like Gramme's or especially Lachaussée-Lambotte's, and, to stifle the noise of the alternating current, it must be placed in a hermetically closed lantern. The luminous point is absolutely fixed, and the light is perfectly steady —two very important advantages of this lamp. A further advantage is the very considerable time during which the lamp can act without stoppage, without renewal of carbons, and without any personal attention. The length of the carbons can vary from 5 to 30 centimetres, and the lamp can act for 15 or 16 consecutive hours if necessary.

The marble block between the two carbons is likewise wasted; the very high temperature to which its lower part is exposed causes a decomposition of the calcic carbonate; quicklime is formed, which is rendered incandescent by the arc. A marble block can last for 20 consecutive hours, or for two lighting periods of 10 hours; it does not last so long if the lighting periods are of two or three hours respectively, and the lamp is thus subjected to a series of lighting and extinction.

The length of the arc varies from 10 to 60 millimetres, according to the resistance for which it is intended. For a short circuit a stronger current and a thinner marble are required; for a long circuit, less current, a higher tension, and a thicker marble must be employed. The lamps commonly used in practice have a slab of marble, or of magnesia, of from 10 to 20 mm. thickness.

Latterly, condensed magnesia has been substituted for marble, because it lasts much longer; it is not decomposed by heat, and can last for a hundred hours; it gives however a white light.

It is of great importance that the blocks of refractory substance should last for a long period, and the inventors have devoted special attention to this point. They have succeeded in constructing blocks which last from 30 to 35 hours, and for this purpose have subjected the refractory material to a previous trial in an apparatus which reproduces as near as possible the conditions to which they are subjected in the lamp itself.

By using the Lachaussée-Lambotte machine, the current can be divided into several circuits, each of which contains several lamps in series; by means of a commutator the current can easily be switched off to an adjacent lamp. Although there is very little chance of extinction, an automatic cutout constructed by Street and Macquaire provides even against this contingency.

To obtain an automatic relighting of the lamp after extinction, Clerc has placed the carbons in a horizontal position and opposite one another (Fig. 78).

The carbons are placed inside the holders *k* and can be fed forwards by means of the spiral springs *s*. One of the two carbons is hollowed out along its entire length, and within the hollow is a thin carbon stick *c* joined to a lever *h*. This lever oscillates through the action of the current on the core *e* of the wire spiral *s* and of the counterweight *g*. When at rest, the weight *g* presses the carbon stick *c* against the unperforated carbon; as soon as the current circulates, the iron core *e* is sucked into the interior of spiral *s*, the little stick *c* and the counterweight follow this motion, and the arc is established and maintained by the hollow carbon upon the continued retrogression of *c*. This process is repeated on the extinction of light, or in case of any interruption of the circuit, which is connected to the two terminal screws k_1 k_1.

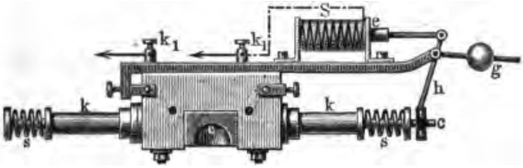

FIG. 78.

The lamp has the great advantage, that it is not sensibly affected by variations of current, it gives a steady light and is not expensive. It has been observed that even considerable and sudden variations of current strength were not perceptible on account of the incandescence of the marble, and that the light was only extinguished after the current had been reduced to half its normal strength; and also, on the other hand, an increase of current strength to three and four times its normal value exercised no disturbing influence.

Tests published in the *Electrotechnische Zeitschrift*, No. 8, 1882, showed the following results:—

No. of Test.	No. of Lamps in circuit.	Diameter of Carbons in millimetres.	Current ampères.	Motive power per lamp, H.P.	Illuminating power per H.P. in candles.
1	16	11	5·0	1·1	547
2	12	11	11·2	1·5	540
3	3	30	6·2	2·6	448
4	2	35	22·5	4·2	1053

The light intensity is stated to have been very large at the commencement, to have gradually decreased within half an hour, and then to have remained nearly constant; the current is said to have diminished nearly in the same ratio as the intensity of light.

Test No. 3 was obtained as the mean of the following experiments:

Motive power expended in H.P. .	9·4	7·0	6·5	7·2	8·5	7·8
Resistance in lamp circuit in ohms	4·8	9·5	13·4	22·9	37·2	55·3
Current in ampères . . .	8·13	6·9	6·4	5·8	5·3	4·6
Motive power per lamp in H.P. .	3·1	2·3	2·2	2·4	2·8	2·6
Illuminating power per H.P. in candles	494	585	576	456	304	281

From this the resistance in the arc seems to be very considerable, and the mean to be between 16 and 17 ohms.

PART III.

GLOW LAMPS.

We have already, on p. 6, shortly explained the difference between arc and glow lamps; it has there been stated that in the glow lamp a moderate conductor opposes to the passing current a considerable resistance; that, in consequence of this resistance, a large portion of the passing energy is transformed into heat, and that the heat generated raises the conductor to incandescence. The lamps themselves which make practical use of these heat effects must be divided into two groups:—

1. *Lamps which combine incandescence and combustion.*
2. *Lamps purely incandescent.*

In the lamps of the first group two electrodes are in imperfect contact; the current thereby meets with a high resistance, and consequently produces heat effects, which manifest themselves in the incandescence of one electrode and the formation of a number of very small arcs between the uneven parts of the electrodes in contact.

The first practical lamp of this class was constructed in 1877 by Emile Reynier.

1. *Reynier's Lamp.*

Reynier was led to the construction of his lamp by making experiments on incandescence with some Russian lamps which will be mentioned hereafter. All these lamps had one and the same serious defect—the waste of the central part of the carbon, which brought about its rupture, and necessitated the substitution of a fresh carbon.

Reynier was led to believe that, if the extremity of the carbon point touched another massive carbon, the waste would occur at the point of imperfect contact where the temperature was highest, on account of the electrical resistance due to this imperfect contact.

If the carbon was burned at its extremity, it only required pushing upwards, like the candle in a carriage lamp. The combustion of the carbon even increased the light, the heat produced by it being instrumental in keeping up a very high temperature. The characteristic part of Reynier's apparatus is, therefore, a carbon point abutting against a fixed contact and rendered incandescent between this point of contact and another, situated at the same distance from the first. The first lamp was worked with four Bunsen elements (Ruhmkorff's model), a Gramme's laboratory machine, or even with a secondary battery of three Planté elements.

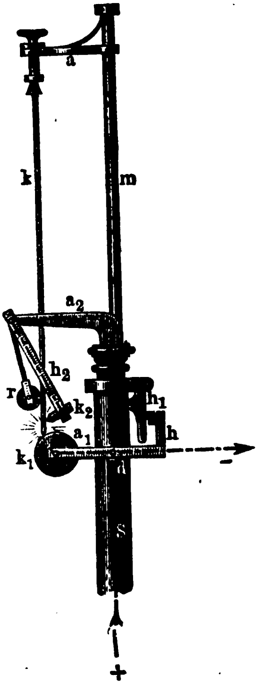

Fig. 79.

In his first experiments, Reynier found that the fixed immovable carbon against which the incandescent carbon pressed did not answer its purpose. He therefore gave it the shape of a disc, which slowly turned round on its horizontal axis, and after constructing a number of lamps of different form, he finally arrived at the model shown in Fig. 79.

The metal rod *m* slides within the hollow metallic column S between a number of small rollers; a horizontal bar *a* fastened to *m* carries the carbon pencil *k* of two mm. thickness. This latter abuts against the circumference of a carbon disc k_1, which is rotated about a_1, by the pressure exercised by *k*. The bar a_1 itself is at *d*, in movable connection with column S, and terminates in a piece *h*, which, when there is a sufficient pressure on *k*, leans so strongly against the lever *h*, that a part of this latter protruding into column S presses against the sliding rod *m* and prevents it from sinking down, at the same time diminishing the pressure of the carbon pencil *k* on the disc k_1.

The carbon pencil traverses the arm a_2 of the column S, and is supported on either side by two levers in movable connection with a_2. One of these levers h_2 carries a small carbon pencil k_2, which presses against one side of carbon pencil *k*, whilst the other lever carries a small copper disc *r*, which presses against the other side of *k*. As indicated by the dotted lines, the current passes from the dynamo through column S, over a_2, h_2, k_2 through the point of carbon pencil *k*, carbon disc *k*, and its metallic holder, back to the dynamo. The greatest resistance on this path is at the point of carbon pencil *k*. Here the incandescence begins, and remains restricted through the influence of pencil k_2, to the distance between *k*, and the point of k_2, which amounts to about five to six mm. The particles burned in the oxygen of the air are replaced by the descent of carbon pencil *k* or of rod *m*, the friction of rk_2 on the one hand, and of *h* on the other, retarding the motion of the carbon pencil, and thus preventing it from being broken, whilst through the rotation of disc k_1, impurities, such as slake or ashes, are kept away from the point of contact. A pencil of 30 cm. is stated to burn for two hours.

Fontaine has obtained with a battery of 12 Bunsen elements a light of 150 candles. A dynamo driven at a speed of 900 to 930 revolutions per minute feeds five lamps of 114 candles, each in series, or ten lamps of 38 candles each, whilst with the same dynamo an arc lamp of 2,400 candles can be fed.

Reynier has also provided his lamp with an automatic relighting arrangement, which makes the lamps of one circuit practically independent of one another.

2. *Werdermann's Lamp, improved by Joël.*

The original lamp constructed by Werdermann is similar in principle to Reynier's lamp; the position of the apparatus, however, is reversed. The negative carbon, placed in the upper part, consists of a carbon disc of large diameter; the positive carbon is an ordinary carbon pencil of four and a half millimetres diameter. A simple spring ensures a permanent contact of the carbon with two positive electrodes; the carbon is pushed by a weight in proportion to its waste. In the improved model, the light is likewise produced by the heating to incandescence of the end of a small rod or pencil of carbon forming one electrode, which protrudes through a pair of contact jaws, and abuts upon a fixed cylinder of copper forming the other electrode. The carbon pencil consumes at the rate of two and a half to three inches per hour, for lights of 100 candle-power and upwards, and is pushed forward according to the consumption. The length of carbon in circuit between the contact jaws and the fixed electrode is about three-quarters of an inch; and this, by the passage of the current, is rendered highly incandescent, chiefly, however, at that part near the copper electrode where the pencil becomes pointed, and therefore more intensely heated. There is also, in addition to this, a glow or flame-like appearance from the sides of the consuming carbon to the copper electrode, the light thus apparently taking an intermediate position between the purely incandescent system and that of the arc. The heated point of the carbon becomes curled at the tip in a peculiar manner, as though it were viscous, in shape somewhat like a mushroom, where it wastes away, and is replaced by the gradual forward motion of the pencil. The fixed electrode, which may be entirely of copper, or with a graphite insertion, remains intact without any appreciable wear. The chief improvements in this lamp consist in the simplification and certainty of action of the mechanism in connection with the contact jaws for clamping the carbon pencil, by which means the lateral pressure of the jaws and the feeding of the carbons are attained by the combined action of one actuating weight, so that the lateral pressure is always proportional to the downward pressure, and may be varied to suit any conditions. The details devised for rendering the lamps in the same circuit independent of each other, and its general adaptability for interior and domestic lighting, constitute an important advance.

There are ingenious arrangements attached to this system for switching a lamp on or off, with resistances equal to that of the lamp.

According to Professor Adams, an illuminating power of 715 candles per horse-power can be obtained with this system. The lamp burns for seven or fourteen hours, according to the dimensions of the carbon.

Various Lamps.

A number of lamps have been constructed since Reynier's and Werdermann's, founded on combined incandescence and combustion of carbons. We only mention a few which differ from their prototypes simply by some details of construction or arrangement.

Trouvé has constructed a lamp in which we find the ascending carbon, the rotating carbon abutment, and the carbon point wasted at its pointed extremity, as in Reynier's lamp. By employing carbon points made of very fine carbon, a light of several carcels can be produced with six Bunsen elements.

In Ducretet's lamp the carbon is pushed upwards by a column of mercury, into which it is immersed.

This apparently simple arrangement, which is already indicated in Reynier's patent, has the drawback of giving off mercurial vapours, in spite of all the precautions that have been taken to prevent the heat of the incandescent carbon from reaching its surface.

Finally, Tommasi, in 1879, constructed a Reynier's lamp under the name of Revolver lamp, in which a certain number of short carbons are arranged in a circle round an iron tube, three centimetres in diameter, and turning on a pivot. A clocktrain successively places each of these carbons in circuit, which gives to the light a certain duration. None of the semi-incandescent lamps have found extensive practical application; they have, however, a much higher efficiency for the same amount of power expended than the purely incandescent lamps (about 3:1), and with improved construction may yet have a future in store for them. Of much greater importance are the lamps of the second group.

Glow Lamps.

These lamps are constructed on the principle of raising the temperature of a moderate and infusible conductor by the passage through it of a powerful electric current. The intensity of light emitted by a heated body increases in a very large proportion with the temperature, and we need, therefore, only employ a substance with a very high point of fusion to be able to raise it to a very high temperature. It is further necessary that the heat produced by the current should be concentrated within a very small space, to avoid the cooling which is so prejudicial to the quantity of the light produced.

The substances most commonly used for the production of light by incandescence are—platinum, an alloy of platinum and iridium, iridium, and carbon.

The first lamp with incandescent platinum dates back as far as 1841, and was invented by Frederick de Moleyns of Cheltenham.

The idea of employing iridium and its alloys is due to Pétrie, in 1849. In his patent, Pétrie gives the method of preparation of iridium intended for electric lamps.

The idea of using carbon for producing incandescence belongs to King, who patented it in 1845; King, however, it seems, was simply the agent of the real inventor, J. W. Starr, of Cincinnati. Starr was the author of several philosophical works, and it was the great philanthropist Peabody who supplied him with the necessary funds for his experiments, which were made in this country. Starr set up a candelabrum with twenty-six lights, symbolical of twenty-six States of the Union. Faraday admired this first experiment very much, and Starr and King started for the United States soon afterwards. The day after their departure Starr was found dead in his bed.

King pointed out in his patent the advantages of a gas carbon, but in order to prevent its combustion, he placed it in a closed vessel from which the air had been previously exhausted. Two or more of these apparatus could be placed in the same circuit of a current supplied either by batteries or by magneto-electric machines.

In 1846, Greener and Staite took out a patent for a lamp similar to King's. To free the carbon from its impurities, it was treated with *aqua regia.*

After that, electric lighting completely fell into oblivion, till 1873, when a Russian physicist, Ladiguine, took up the question. His researches earned him a prize from the St. Petersburg Academy of Sciences.

The advantages of carbon were on that occasion very clearly defined by the Russian physicist, Wilde, who was entrusted with the report on the award of the prize. He said:

"Carbon has at equal temperature a greater radiating power than platinum, its thermal capacity is much smaller, so that the same amount of heat raises a carbon filament to a much higher temperature than a platinum wire. Moreover, the electrical resistance of carbon is about 250 times greater than that of platinum; the carbon may therefore be made larger while raising the temperature as much as the metal. Finally, carbon is infusible, and its temperature may be raised without any danger of fusion."

Kosloff, of St. Petersburg, who came to France to work Ladiguine's patent, slightly improved the lamp, but without obtaining any satisfactory results.

In 1875 Konn constructed a similar lamp; in 1876 Bouliguine constructed another with a single carbon.

In 1879 appeared the American (Sawyer's) lamp, in which the incandescent carbon was placed in an atmosphere of nitrogen, in order to prevent its combustion.

In all these lamps, although the carbon does not burn in the true sense of the word, there is yet a sort of disintegration or evaporation, which gradually destroys the incandescent carbon. This evaporation is moreover clearly proved by a deposit of sublimated carbon, in the form of a very fine powder, on the interior surface of the globes, and the different interior parts of the apparatus.

Platinum Glow Lamps.

It has been mentioned on p. 265 that the first lamp of this kind was constructed by De Moleyns in 1841, and a similar lamp by Pétrie in 1849.

In 1857 De Changy invented a system permitting the divisibility of the electric current. According to a letter addressed by M. Jobard, Director of the Musée Industriel Belge, to the Académie des Sciences in Paris, Changy obtained with a battery of 12 Bunsen elements 12 lights of great steadiness and independent of each other; but the terms of the patent are so vague that it is impossible to understand the exact working of De Changy's apparatus.

Edison's Platinum Glow Lamp.

This lamp consists of a spiral platinum wire* traversed by a current. To prevent the fusion of the wire, a metallic rod, placed inside the spiral and heated by it, establishes by its expansion a direct connection; a short circuit is formed between the two terminals of the lamp, and weakens for a short period the current traversing the luminous spiral. The spiral is cooled, and with it the metallic rod, which contracts, and thereby breaks the short circuit. The current traverses anew the spiral platinum, and the same series of phenomena are exhibited. But as these phenomena of heating and cooling are very rapid, Edison's apparatus is little else than an electrical vibratory instrument.

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* Most of the incandescent metallic lamps have spiral wires. The object of this arrangement is to concentrate the heat of the current within a small space, in order to raise the metal to its maximum temperature, and consequently to obtain from it a larger quantity of light. A platinum wire traversed by a current of a certain strength is carried to red heat when stretched out, whilst it reaches white heat when coiled into a spiral.

Edison's Carbon Glow Lamp.

After having unsuccessfully attempted to produce light for practical purposes, by the incandescence of platinum wire traversed by a current, Edison had recourse to specially prepared carbon, and this special preparation constitutes the very essence of his invention.

Edison's lamp, patented in 1879, consists of carbon in the form of a horse-shoe of 5 to 6 centimetres in length, and 3 to 4 millimetres diameter. This carbon is placed in a globe which is subsequently exhausted. The extremities of this carbon are fixed to two platinum pincers, which terminate in two wires of the same metal, connected with the two exterior terminals.

The carbon is prepared by cutting small sheets of brown paper in the form of a horse-shoe; a certain number of these sheets are placed in an iron mould which is gradually heated in a muffle; at the end of the operation the muffle is maintained at a very high temperature during a certain time.

The volatile parts of the paper disappear, and a thin texture of rather fragile paper carbon remains in the mould, which, when placed in the vacuum globe and traversed by a current, can remain incandescent for a certain time.

The life of these lamps, however, was exceedingly limited; the paper carbon could only for a very short period resist the disintegrating action of the current, and was therefore soon abandoned.

In 1880 Edison took out a fresh patent for an improved lamp, and this, with very slight modification, is the one used at the present moment. The chief improvement is the substitution of carbonised bamboo for carbonised paper. These filaments are prepared in the following way:—Canes of this material are first sawn into pieces of the required length, which are, from the character of the plant, naturally tubular. One of these pieces is then split longitudinally down the middle into two half-tubes, each of which is again split into three narrower strips; the hard silicious outer covering peculiar to the plants of the bamboo family is then removed, and the straight fibrous portion is shaved down till it is perfectly straight, flat, and of uniform thickness throughout, when it is cut to the required length. The next stage in the process consists in pressing one of these flat strips between two metal blocks which are accurately surfaced to one another so as partly to project throughout the whole of its length; this projecting portion is then cut away, with the exception of a little piece at each end, so as to have a fine thread of bamboo fibre having enlarged portions at either end; or, if the intended filaments are for the half-lamps, an enlarged portion is left in the middle as well as at the two ends, so that two filaments may be constructed out of the same bamboo strip. The threads so prepared are then laid in moulds consisting of nickel plates, in which grooves are cut of the required horse-shoe form; a flat nickel plate is then fixed over them so as to enclose them and prevent the admission of air during the process of carbonisation, which is effected by raising the moulds with their contents to a high temperature by placing them in a muffle and heating them to incandescence. When the moulds are opened, the filaments are in a condition to be electroplated to their platinum supports, and introduced into the lamp-bulbs; but yet another process is required to confer upon them their perfectly homogeneous and elastic character, as well as their refractory nature at high degrees of incandescence, which are such essential characteristics of a glow lamp. This further process is applied when the lamp is attached to the pump, and while exhaustion is going on; it consists in alternately heating and cooling the filament in the vacuum created by a Sprengel pump, by passing currents of electricity through it of increasing strength, until high degrees of incandescence are reached, and between each increase of current allowing it to cool down, exhaustion going on all the time. By this process, not only are all the occluded gases eliminated, but, as the fibre is subjected to a far more severe test than it can ever be subjected to in working, none but the best survive and a lasting lamp is obtained. The two ends of the carbon filament are connected respectively by means of platinum wires to a screw and a cone, each stamped in thin brass, held at the proper distance apart, and insulated from one another by a filling of plaster of Paris which surrounds the neck of the envelope and forms a firm and rigid attachment. The socket into which this fitting screws, and which is in permanent connection with the conducting mains, consists of a cone of thin brass, below which is a hollow screw, both being embedded in a cylindrical mass of plaster of Paris, and forming a matrix or counterpart of the fitting of the lamp. The action of screwing a lamp into its socket is to draw the cone on the lamp firmly into its seat, and at the same time to press the threads of its helical socket, thus ensuring very perfect metallic contact between the terminals of the lamp and the conducting mains.

A considerable portion of the work of manufacturing the lamps is performed by machinery, by which greater uniformity is ensured; but the chain of operations by which the rough materials are converted into a finished glow lamp is as follows: The closed end of the bulb is heated and drawn out into a hollow cone. To this little cone is then fused a short fine tube, by which the envelope is afterwards to be attached to the exhausting apparatus. The next process is to prepare the glass stem, by which the carbon filament is held in its place within the globe, and within which the platinum conductors are fixed that are to join it to the connecting fittings. A piece of tube is taken, and its two ends are drawn or tapered off. It is then thickened up in two places, between which it is divided into two separate tubes; two platinum conducting wires are then passed through the tube, care being taken that they do not touch one another. The large end is then heated nearly to its point of fusion, and is squeezed flat, so as to cause the platinum wire to be closely embedded within its substance. The little cranked pieces are then soldered to the ends of the wires, and to these are attached, by an electro deposit of pure copper, the ends of the carbon loop described above. The glass stem, with the carbon filament attached, is then introduced into the neck of the bulb, to the mouth of which its thickened portion is attached by fusion, so as to form with it one piece of glass. The drawn-down end is trimmed off square. The exhausting tube is drawn down in two places, so as to form two capillary contractions. This tube having been attached by a mercury joint to the Sprengel pump, the bulb is exhausted, and when the requisite exhaustion is complete, the contraction nearest the pump is sealed up, leaving a short length of tube attached to the capillary neck, but exhausted to the same degree of internal residual pressure. A second sealing up of this neck renders the hermetic closing of the lamp complete, the object of the double sealing being to guard against any leaking into the envelope at the moment of detaching it from the pump; and, by fusing a little globule of glass upon the sealed-up point, all possibility of an opening being left into the outer air, however minute, is removed. Nothing now remains but to attach the terminal fitting to the stem of the bulb, and the lamp of the well-known form is complete.

Efficiency and Life of the Edison Lamp.

All figures and data concerning the efficiency of glow lamps must be received with the greatest caution. These figures were for a long time given on the sole responsibility of the makers; and without for one moment wishing to impugn their good faith, we may safely say that the figures given were in most, if not in all, cases the result of an individual test, or of a small number of tests extending over a short period, and entirely leaving out of consideration that most important point—the life of the lamp.

It is but natural in the case of such a novel apparatus as the glow lamp that accurate and reliable information could only be gained from experience extending over a period of several years (to decide the question of the life of a lamp of 1,000 burning hours, under practical conditions of alternate extinction and lighting, taking eight hours per day as the average working time, tests extending over several months have to be made), and this is emphatically the state of affairs as regards the question of efficiency of the glow lamp. If we look round trying to find authenticated statements on this sore point we must at once admit that not even now are we in a position to pronounce a definite opinion founded on indisputable authority. The Electrical Exhibitions at Paris, Munich, and Vienna have not furnished us the required information; and the results of the tests made by the Franklin Institute of the State of Pennsylvania have only just been published, and their reliability has been openly and seriously attacked by one of the manufacturing firms whose lamps were included in the report. It seems, however, that the objections taken to these tests were based not so much on the grounds of inaccuracy of the methods of testing, as on the fact that the lamps were overdriven; and, after careful perusal of the report, which contains a detailed account of the methods and instruments employed, and further, on the testimony of several eminent electricians, we may fairly conclude that the results obtained are on the whole reliable as regards the Edison lamp.

The tests were commenced on the 11th April, 1884, and were continued without any interruption until the 28th May. Edison lamps varying from 95 to 100 volts indicated were tested, and gave the following results:

Number of Lamps.	Volts (mean).	Ampères (mean).	Watts per candle (mean).	Mean spherical * intensity in candles.
20	97·9	·709	4·48	15·49

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* The mean spherical intensity of a source of light is obtained by taking the middle point of the light as the centre of a sphere, and dividing the sum of the illuminations of the areas constituting the surface of the sphere by the total number of areas.

The number of burning hours of these lamps was 1,065, and the whole of the 20 lamps, with the exception of one which was broken after 295 hours, lasted throughout the time of testing.

Besides these 20 lamps a number of other lamps, all varying between 95 and 100 volts, were tested, and the following figures were obtained as the means of the complete series of experiments:

Volts indicated	96·9
Volts observed	97·57
Ampères	·7065
Watts	68·92
Luminous intensity in candles (mean spherical)	15·47
„ „ (mean horizontal)	19·24
Watts per candle (spherical)	4·459
Candles per electrical horse power (spherical)	169·2
„ „ (horizontal)	210·4

It was further ascertained that the luminous intensity after 1,006 hours had fallen from 15·47 to 9·6 candles (spherical), and from 19·24 to 12 candles (horizontal).

On considering the question of efficiency, we are naturally led to inquire into the conditions to be fulfilled for the successful and economical working of a lamp. We know that the higher the temperature of the carbon filament, the more favourable is the transformation of electrical energy into light, and the smaller the number of watts required for the production of a certain quantity of light. This simple physical fact has in many instances led to the erroneous conclusion, that that glow lamp was the best which, with the least expenditure of work, gave the highest light intensity, entirely losing sight of that most important point—the life of the lamp. From the above quoted results we see that the pretensions of the Edison lamp do not go beyond attaining one candle with an expenditure of from four to five watts. It is of course very easy to obtain a higher degree of incandescence, and consequently to produce a unit of light with less work; but whether the advantage of greater brilliancy is not more than counterbalanced by a proportional larger consumption of lamps, is another question. It is clear therefore that under certain given conditions a definite and distinct efficiency of the lamps of an installation must recommend itself as the most rational from a practical point of view. In all cases where the life of the lamp is not the only paramount consideration, the question as to the number of watts to be expended for producing unit of light resolves itself into one *of reducing to a minimum the total annual expenses per candle.*

How the illuminating power affects the life of the Edison lamp will be seen from the following table, which we take from the *Electrotechnische Zeitschrift*, August, 1884:—

Illuminating power, in Candles.	Life in hours.	
	10-candle lamp.	16-candle lamp.
8	2,260	..
9	1,470	..
10	1,000	5,550
11	714	3,963
12	512	2,857
13	385	2,134
14	294	1,628
15	233	1,292
16	179	1,000
17	145	802
18	118	651
19	96	534
20	80	443
21	..	371
22	..	312
23	..	266
24	..	228
25	..	196
30	..	163

But what we want to know is, not so much the relation between illuminating power and life of the lamp as between the energy to be expended per candle and the life; and for this purpose we have first to find the relation between the illuminating power and the energy expended. The Commission of the Munich Electrical Exhibition has made the necessary investigations on this point, and found for the Edison 16-candle lamp— e

$$L = \cdot 0000376 \times (c\,\cancel{l})^3 = k \times (c\,e)^3,$$

where L is the life, c the current and e the E. M. F. of the lamp; therefore energy of lamp (E)—

$$E = \frac{c\,e}{L} = \frac{1}{\sqrt[3]{k\,L^2}}$$

With the aid of this equation we can compile the following table for the Edison 16-candle lamp:—

Watts per candle.	Burning hours.	Watts per candle.	Burning hours.
6·43	5,550	4·19	534
6·04	3,963	4·05	443
5·69	2,857	3·92	371
5·40	2,134	3·80	312
5·14	1,628	3·69	266
4·91	1,292	3·59	228
4·70	1,000	3·49	196
4·52	802	3·09	163
4·35	651		

The Swan Lamp.

The first glow lamp shown in England was Swan's, who exhibited it at a meeting of the Society of Telegraph Engineers on the 24th November, 1880.

The lamp shown on that occasion consisted of a glass globe containing two split metal tubes with tightening rings, exactly like the brass crayon-holders which were formerly used for drawing. The carbon filament, much thicker at the two extremities, is bent to the shape of a flat helix, so as to form a ring in the centre of the glass globe. The material and preparation of these filaments of carbon are different from those of the Edison carbons. They are made of strings of cotton about ten centimetres in length, the ends of which are thickened by winding some additional cotton round them. These strings are immersed in sulphuric acid (two parts of acid to one of water), and after some time assume the compactness and hardness of parchment. They are then removed, and quickly and thoroughly washed in water so as to remove the last trace of acid, and passed through discs, which reduce them to a uniform cross section. Before carbonization the filaments are wound on rods of carbon or earthenware, so as to give them the required form. They are then placed in a crucible filled with powdered charcoal, and raised to white heat for a certain time.

The filaments are then inserted into the metal jaws, and clipped tightly by means of the sliding rings; the two tubes are continued as half tubes, and form the conductors by which the current is conveyed to the carbon. They are supported by being tied to a glass rod which forms part of the neck of the lamp. Platinum wires are attached to the upper ends of the metal tubes, and pass out through the glass being melted into it. In order to prevent any leakage, little platinum caps are fixed to the wire just where it comes through the glass, and melted on the glass outside.

The reason of having so long a neck to the lamp was that it was thought, if it were shorter, sufficient heat might be conducted from the carbon to the platinum wire and cap to risk cracking the glass. The air is then exhausted from the bulb by means of a Sprengel, or other pump, the carbon being heated to incandescence while exhaustion is going on, in order to drive out all the gases which might be contained in the carbons. After this operation, which may last half an hour, the lamp is closed with the blow-pipe, and is now ready for use.

For convenience in attaching the lamp to the wires bringing the current to it, the stem of the old lamp was enclosed in a cardboard tube about $\frac{1}{8}$-inch thick. Brass springs attached to the two sides of this tube were connected respectively to the two platinum caps by means of two little screws.

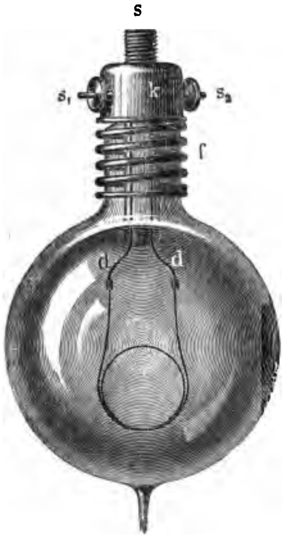

Fig. 80.

At the end of the wall-bracket, or other stand, which carried the lamp, was fixed a wooden tube, into which the paper tube on the lamp just fitted. Inside this wooden tube were two metal plates, to which were attached the wire supplying the current. When the lamp was put into position, by having its stem slid into the tube, the springs pressed on the metal plates, and at once made the connection.

The 20-candle lamps of the old pattern had a resistance of from 45 to 150 ohms when cold, or 25 to 75 ohms when hot. They required from 1 to $1\frac{1}{2}$ ampères current, and 30 to 50 volts E. M. F.

The most recent form of the lamp, 1883 pattern, is shown in Fig. 80; it has a much longer and thinner filament than in the old pattern, being about 5 inches long and ·005 inch in diameter. The exterior of the lamp is entirely of glass, and from the short stem at the top project two small platinum loops (not shown in the figure), the terminals *d d* of the platinum wires carrying the carbon filament. The lamp connection consists of an ebonite stud *k* with a screwed plug *s* for attachment to a gas bracket or other stand; on each side of the stand are the binding screws s_1 s_2 and in connection with them are two small platinum hooks (not shown in the figure) projecting from the stand. Attached to this latter is also a light spiral spring *f*. Fig. 80 shows the lamp connected up, and from this figure it will be seen that the loops of the platinum terminals are passed over the platinum hooks on the stand, compressing the spiral spring round the neck of the lamp, and thus making a most efficient fastening, in which the electrical contact is perfect, and at the same time there is a total absence of rigidity. The only objection to this mounting is the frequent breakage of the platinum loops, which are necessarily of very fine wire.

The following are the results of some experiments in the efficiency of the new Swan lamp:—*

Candle power of lamp.	Current in ampères.	E. M. F. in volts.	Resistance in ohms (Holt).	Watts per Candle.	Candles per H.P.	Lamps per H.P.
16	·62	98	158	3·74	199	12
16	·63	97·1	154	3·69	202	12
16	·726	78	107	3·5	213	12
18	·63	100	158·7	3·5	213	12
18	·64	99·1	154·8	3·52	212	12
18	·75	80	107	3·3	226	12
20	·65	102	157	3·32	225	11
20	·66	100	151·5	3·3	226	11
20	·76	82	108	3·1	240	12

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* From J. E. H. Gordon's 'Practical Treatise on Electric Lighting.' Part of the description of the Swan lamp is also taken from this book.

Some further details of installation will be found in Part III., p. 362, and also an account of the latest form of Swan's mining lamp on p. 356.

The Lane-Fox (or Victoria) Lamp.

In the diagram of the lamp, (Fig. 81) *k* represents the luminous conductor, which consists of a carbon filament prepared by baking a grass fibre, in a hermetically sealed vessel at white heat.

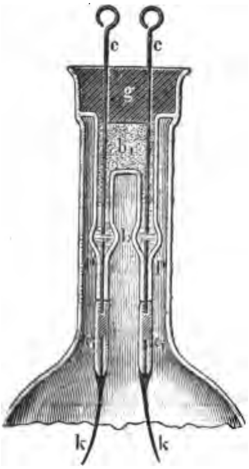

Fig. 81.

In order to reduce the resistance of the filament, and to produce a harder and more durable carbon, Lane-Fox adopted a plan, first suggested by Sawyer of New York, of heating the conductor to incandescence whilst immersed in a hydrocarbon liquid or gas. Referring again to the diagram, k_1 k_1 are carbon cylinders, into which the ends of the carbon filaments are secured. A small hole is drilled through these cylinders, and into these holes the ends of the carbon thread fit tightly. A very good cement for fixing these carbons may be made out of plumbago and Indian ink. The ends of the copper conducting wires are bent into eyes *c c*, into which the hooks of the holder are inserted. These copper wires, as well as the platinum wires *p p*, dip into a small basin of mercury *b*, whilst the space b_1, above the mercury, is filled with cotton wool; a layer of gypsum *g* closes the lamp. The filament employed in these lamps is made from grass fibres, preferably that known as French whisk, or bass broom, and used in making certain kinds of carpet brooms. The fibre is first cleaned by boiling in a strong solution of caustic soda or potash, and the outer skin scraped off.

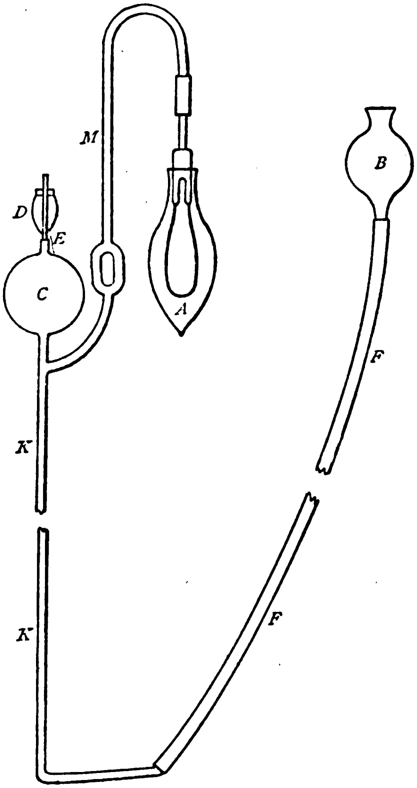

FIG. 82.

The soda or potash is then boiled out of it, and a number of fibres are stretched round a mould or shape of plumbago, and are then baked in a plumbago crucible at a white heat. After being baked in this manner, the fibres are further carbonized by depositing carbon upon them from a rich hydrocarbon gas, such as benzole. For this purpose they are suspended in large globes filled with benzole or coal gas, and then heated to incandescence by the current. The white-hot filament decomposes the gas, and carbon is deposited on its surface, especially at the thinner parts, where the temperature is highest. In this way the fibre is covered with a skin of hard carbon, which brings it to the required resistance and renders it more uniform throughout, a point of some importance as affecting the durability of the filaments. Instead of employing the electric current in this way, Mr. Lane-Fox carbonized his filaments by raising the benzole receptacle to white heat in a furnace.

After being carbonized in this manner, the fibres are classed according to their thickness, and are ready for mounting in the lamps. Slight differences of thickness occasion great differences in resistance, and the thicker specimens are reserved for lamps of 30 to 60 candle-power, whilst the smaller ones are kept for lamps of 10 to 20 candle-power.

The exhaustion of the bulbs is effected by a very simple and ingenious mercurial air-pump, invented by Mr. Lane-Fox. It consists (Fig. 82) of a vertical glass tube K, terminating in a bulb C, at the upper end of which is a ground neck D, with stopper E. At the lower end of the glass tube K is attached a strong flexible tube F, of greater length, to the other end of which is fitted an open glass vessel B. To the glass tube K, just below the bulb C, is connected a vertical tube M, which is connected with the lamp A to be exhausted.

The action of the pump is as follows: The vessel B having been filled with mercury when in a lowered position, is raised to such a height that the vessel C is filled. The neck of C is then closed with the stopper E, and the vessel B lowered to allow the mercury to fall well below the junction of tube M, which produces a partial vacuum. The vessel B is then raised, the stopper E being removed to allow the air to escape.

This operation is repeated till a complete vacuum is produced in the lamp, and is continued while the filament is maintained in a state of incandescence, when the tube connecting the lamp is fused off by the glass-blower.

The Maxim Lamp.

The filament, which is of the shape of an M (Fig. 83), is made of carbonized cardboard. The globe is exhausted, and a certain quantity of hydrocarbon vapour (gazoline) introduced, then the globe is again exhausted whilst the current passes, and the operation repeated until all the air is expelled. It has been proved by experience that by the passage of the current the rarified vapour of gazoline has a renovating effect, by depositing its carbon on the most incandescent, that is to say, the thinnest parts of the filament. The filaments are connected to the platinum pincers by means of soft carbon, which gives an excellent contact. The conductors are sealed into a special enamel which has nearly the same coefficient of expansion as platinum; this prevents cracks and contributes to the tightness of the apparatus. The lamps are fixed to an

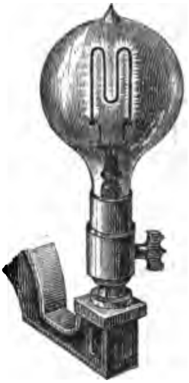

Fig. 83.

ebonite mounting, which terminates in a pedestal of German silver; this latter can be screwed on a gas-bracket instead of an ordinary burner.

The Weston Glow Lamp.

Whilst Edison sticks to bamboo fibre as material for his carbon filaments, and lays stress on the fibrous structure of the carbon, Weston's endeavour is to obtain an entirely structureless, amorphous material of vegetable origin, and consequently of high specific resistance. This purpose he effects by exposing the cellulose of cotton or linen fibre to a mixture of nitric and sulphuric acid, thereby converting it into nitro-cellulose or gun-cotton. The latter is, by dissolving it in a mixture of alcohol and ether, converted into collodion, and when in that form cut into thin plates (about ·1 mm. thick), and finally by treatment with a reducing agent, such as ammonium hydrosulphide, deprived of its property of complete combustibility.

The substance thus prepared—called "Tamidine" by Weston, in reality amorphous cellulose—is of amber colour, great toughness and ductility. It is nearly homogeneous, and shows no structure even under a powerful microscope. The further treatment is a mechanical one, namely, rolling it out between very strong steel rollers, and stamping out the curved filament with stamping moulds of very accurate workmanship. This filament is then carbonized in the usual way at a very high temperature, and a carbon thread is thus obtained, whose specific resistance is considerably higher than that of any fibrous substance or of any material prepared from an inorganic body. The finished carbon filament resembles a steel spring in elasticity, is of brilliantly black colour and of smooth surface. In stamping out the filament a comparatively broad slip is left at each extremity, and to this the platinum wires are fixed, which connect the lamp to the leads of the circuit.

Weston makes lamps of from 16 to 600 candles; his object in constructing lamps of such high illuminating power is to obtain an intermediate apparatus between an arc and an ordinary glow lamp which is to combine the advantages of the two systems, and to avoid those drawbacks, namely, the greater cost of the latter, and the want of steadiness of the former.

Lamps of 125 candles, mounted in lanterns, are used for street lighting in the United States; they are provided with a compensating resistance contained in the upper part of the holder, and corresponding to the resistance of the lamp itself. These lamps take 160 volts and 2·3 ampères, or nearly 3 watts per candle; they give 250 candles per horse-power. The lamps are connected in multiple series of four lamps each; as stated above, each lamp is provided with a compensating resistance, which, on the extinction of the lamp, is inserted in the circuit, and each series of four lamps has an automatic cutout for switching it off should all the four lamps be extinguished.

The tests made by the Franklin Institute gave the following results for the Weston lamp:—

Number of lamps tested	20
Current in ampères	·530
E. M. F. in volts	111·4
Illuminating power in candles	16·27
Watts per candle	3·63

Six only of these lamps lasted during the whole time of testing, namely, 1,065 hours.

Another class of lamps of 70 volts were tested, and run for 524 hours with the following results:—

Number of lamps tested	10
Current in ampères	·968
E. M. F. in volts	70·4
Illuminating power in candles	15·18
Watts per candle	4·51

Seven out of these ten lamps lasted during the time of testing, namely, 524 hours.

The Woodhouse and Rawson Lamp.

Instead of a carbon thread, a thin riband is used as conductor in this lamp. As far as could be ascertained (the whole of the manufacturing process is kept secret by the makers), the raw material for the filament is cotton, and the deposition of carbon from a hydrocarbon decomposed by the current is a main feature of the lamp. In some instances, lamps of very high efficiency were turned out by the manufacturers. Mr. Preece, in his report to the City Commissioners, gives the following figures about two kinds of lamps:—

E. M. F. in volts	55
Current in ampères	1·15
Candles	20·2
Watts per candle	2·35

And another lamp gave the following results:—

E. M. F. in volts	60
Current in ampères	2·33
Candles	53
Watts per candle	2·4

We have no reliable information as to the life of these lamps, but it is doubtful whether it is advisable to burn them at less than 3 watts per candle. Messrs. Woodhouse and Rawson have objected to the tests made by the Franklin Institute, on the ground that their lamps were worked with an E. M. F. of 55 volts instead of 50 volts, and under these circumstances the tests cannot be considered conclusive as to the life of the lamps. The efficiency was found to be 3·4 watts per candle.

The Siemens and Halske Lamp.

The manufacturing process of this lamp is to a great extent kept secret. The lamps tested at the Munich Exhibition had a filament of compressed graphite, which had been subsequently improved by the method fully described in the next paragraph. Their latest types of lamps give the following results:—

Type of lamp.	IA.	I.	II.	II.	IV.	IV.	IV.	IV.	VI.	VI.	VI.	VIII.	X.
Candles . . .	5	8	10	10	16	16	16	16	25	25	25	35	50
E. M. F. in volts .	25	50	100	65	120	100	65	50	120	100	65	100	100
Current in ampères .	·77	·55	·39	·54	·50	·53	·77	1·06	·75	·77	1·17	1·12	1·50
Resistance (Hot.) in ohms . .	32·7	90·9	256	120	240	189	84·4	47·1	160	130	55·5	89·3	66·6

The 16-candle 120-volt lamp is, on account of its high resistance, specially adapted to central stations, because it allows of a considerable economy in the heavy expenditure of the conductors. These lamps, as well as the 68-volt types, are chiefly intended for those installations which employ arc and glow lamps in one circuit. The latter E. M. F. must be chosen when single arc lamps (whether of 3, 6, 9, 20 or more ampères) are placed in parallel with the glow lamps; the former E. M. F. must be adopted when two arc lamps in series are to be connected in parallel with the glow lamps.

The candle powers given in the above table are mere horizontal light intensities, such as are usually given in practice. Repeated tests have confirmed the observations of the Commission of the Munich Exhibition, viz., that with lamps employing a filament of circular cross section one measurement taken at any angle about the vertical axis is sufficient; whilst with the Edison lamp, which has a filament of rectilineal cross section, two measurements ought to be taken at different angles about the vertical axis, and the mean of the two ought to be adopted. For the first measurement the lamp is generally adjusted in such a way that the two halves of the filament nearly cover each other; whilst for the second measurement the plane of the filament is placed nearly perpendicular to the axis of the photometer.

The Cruto Lamp.

The characteristic feature of this lamp is the construction of its filament. A platinum wire of about $\frac{1}{100}$ mm. diameter and cut to the proper length is bent in form of a horse-shoe, the extremities are inserted into metallic pincers insulated from one another, and the wire is then placed in a long glass vessel, through which circulates a current of pure hydrocarbon. The gas employed is olefiant gas, $C_2 H_4$, prepared from a mixture of $\frac{1}{3}$ alcohol and $\frac{2}{3}$ of sulphuric acid (free from sulphur). Before entering the collecting gasometer, the gas is purified by passing it through water and lime water, and also dried by means of calcium chloride and Nordhausen oil of vitriol.

Each vessel is placed in a shunt on the circuit of a Gramme machine, and the current can be regulated by means of a graduated resistance ranging from 1 to 200 ohms. As soon as the current passes, the platinum wire is raised to incandescence, and decomposes the hydrocarbon. Carbon is deposited on the platinum, and in proportion as the diameter of the filament is enlarged, its resistance decreases, and as soon as it has reached a certain point which, according to the requirements of the lamp, has been determined beforehand, the operation is stopped, and the filament is ready for mounting. In order to ensure a uniform deposition of carbon along the whole length of the platinum wire, this latter, which is subject to the influence of the magnetic action of the earth, must be placed in a plane at right angles to the needle of an inclination compass placed in the magnetic meridian, and further, when the filament assumes a certain consistency, the current must be inverted, care being taken however that this inversion is not effected too soon.

If the successive deposits of carbon are obtained in a uniform manner, the resulting filament is homogeneous and compact; if, on the other hand, they are not effected under the same conditions, a filament is produced, consisting of a number of individual superposed layers, and perfectly useless for practical purposes. The manufacturing of the filament takes, on an average, about two hours and a half.

There can be no question that the filaments obtained by this method are most uniform in length, cross section and resistance.

The next operation is to attach the filament to the platinum wires which are sealed into the lamp bulbs. For this purpose the extremities of the platinum wires are formed into thin tubes, the filament is inserted into the opening and then introduced into the bulb containing the hydrocarbon. The current is passed again, and the carbon deposited on the incandescent platinum makes an excellent cement, which has never been known to fail.

The subsequent operations, namely, of placing the filament in the lamp bulb, of exhausting the air, and of mounting the lamp, are identical with the corresponding processes of other systems, and therefore need no further description.

The following lamps are manufactured by Messrs. Milde & Co., at Posiasco.

No.	Candles.	Volts.	Ampères.	Watts per candle.
1	4	5	2·80	3·5
2	8	10	2·80	3·5
3	12	50	·85	3·5
4	16	50	1·05	3·15
5	50	50	2·25	2·25
6	100	100	2·25	2·25

The objection to these lamps is that they take too large a current, and therefore do not lend themselves to distribution of light as readily as lamps of light resistance.

The Bernstein Lamp.

In this lamp, as in the preceding one, the peculiarity consists in the construction of the carbon conductor; we have no longer to do with a solid filament but with a hollow carbon cylinder, presenting a larger illuminating surface, and consequently giving a higher light intensity.

The material from which the carbon is prepared is an exceedingly fine hollow riband of woven silk. It will be remarked that this is the only system employing an animal fibre instead of a vegetable one. The advantages of the material consist in its greater elasticity. The silk is cut into pieces of proper length and immersed for some time in a thick syrup prepared by solution of cane sugar in water. On being removed from the syrup, the silk riband is immersed in melted paraffin, and, after cooling, twisted round a cylindrical block to give it the required horse-shoe shape. Five or six of these carbons are then placed in a graphite mould cut to shape, and embedded in graphite powder, and baked in a furnace for twenty-four hours.

The remainder of the process is in all its points completely identical with that of the Lane-Fox lamp; the flashing or improving in coal gas, the exhaustion by means of the Lane-Fox pump are strictly followed; whilst the connection of the carbon with the platinum wire is that recommended by W. Siemens, namely, forming the extremities of the wire into a helix, inserting the carbon, and either nickel-plating the jointure, or using for the junction a cement made of gum, syrup, and powdered graphite.

The lamps in the market up to date are exclusively high candle-power lamps, for which purpose they are specially fitted.

Lamp.	Candles.	Volts.	Ampères.	Watts per candle.
A.	66	45	4·5	3
D.	33	25	4·5	3·4

The objection to these lamps is, as in the case of the Cruto lamp, the large current which they take, and which renders their parallel connection, if not impossible, yet difficult and expensive.

Mr. Bernstein has proposed ('Journal of the Society of Telegraph Engineers,' March 25th, 1886) to connect his low resistance lamps in series, and provide each lamp with a resistance which would be automatically switched into the circuit upon the extinction of the lamp. This method, which is similar to that of Weston's (v. p. 289), would render the lamps independent of each other.

A number of other glow lamps have from time to time made their appearance without being able to obtain a firm footing; amongst them we may mention the Gatehouse, the Crookes, the Müller, etc.

The latest glow lamp is the *Puluj lamp*, manufactured at Steyr in Austria; the material for the carbon filament is manilla hemp, and for the flashing operation the filament is immersed in a liquid hydrocarbon, an operation already patented by Lane-Fox.

*Glow Lamps at the Vienna Exhibition.**

Two separate series of tests were made; the one with the view of determining the relative luminous intensities radiated by a glow lamp in different directions of a room, the second for finding the ratio between the quantity of radiated light and the expended electrical work. We are here chiefly concerned with the second class of tests, of which we give a "résumé" in the following tables:—

The following lamps were tested:

1., Edison; 2., Swan; 3., Lane-Fox; 4., Siemens; 5., Maxim; 6., Woodhouse and Rawson; 7., Bernstein; 8., Cruto; 9., Gatehouse; 10., Greiner and Friedrichs; 11., Müller; 12., Ladiguine (Jablochkoff).

Columns 3, 4, 5 contain the results of direct measurements, from which columns 6, 7, 8, 9, are calculated. The tables only give the conditions of working at or near the normal candle-power; column 10 gives the coefficient of reduction for mean spherical intensity (v. footnote, p. 277).

In order to find the mean spherical intensity, the observed candle power has to be multiplied with this coefficient.

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* 'Bericht der wissenschaftlichen Commission,' Wien, 1886, p. 65.

1. Edison Lamp.

Number of Lamps tested: 5.
Normal Candle-power: 16.

Name of Lamp.	Number of Lamp.	Candle-power observed. l	Current in Ampères. c	E. M. F. in Volts. e	Resistance (hot) in Ohms. $r = \frac{e}{c}$	Electrical work in Watts. $e\,c$	Watts per Candle. $\frac{e\,c}{l}$	Candles per H. P. $\frac{736l}{e\,c}$	Coefficient of Redu	Remarks.
Edison .	1	14·1	·494	113·3	229·1	55·98	3·98	185		
		18·2	·516	117·5	227·8	60·62	3·34	221		
	2	16·3	·528	119·1	225·7	62·85	3·85	191		
	3	15·6	·490	111·9	228·3	54·85	3·51	210		
	5	16·4	·550	117·1	211·1	64·97	3·96	186	·74	

2. Swan Lamp.

Number of Lamps tested: 12.
Normal Candle-power: 10 and 16.

Swan .	1	9·0	·655	52·02	79·46	34·06	3·77	195		
	3	7·6	·627	49·39	78·77	30·97	4·10	180		
	,,	9·0	·648	50·90	78·55	32·99	3·65	201	·82	
	5	16·1	1·074	47·65	44·37	51·17	3·18	231	·94	
	6	18·8	1·146	48·70	42·38	55·83	2·98	247		
	7	14·4	1·074	46·66	43·46	50·10	3·48	212		
	,,	19·4	1·141	49·06	43·11	55·83	2·88	256		
	8	14·5	·636	100·4	157·8	63·85	4·41	167		
	,,	18·3	·665	104·3	156·7	69·37	3·79	194		
	9	14·5	·614	94·34	153·7	57·92	4·00	184		
	,,	17·0	·633	96·80	153·0	61·23	3·59	205		

3. Gatehouse Lamp.

Number of Lamps tested: 3.
Normal Candle-power: 16.

Gatehouse .	1	13·8	1·047	45·72	43·67	47·88	3·46	213		
	,,	18·5	1·098	48·00	43·72	52·70	2·85	258	·82	
	2	14·8	1·066	47·24	44·32	50·36	3·41	216		
	3	15 3	1·129	53·15	47·08	59·99	3·92	188	·74	

4. Greiner and Friedrichs Lamp.

Number of Lamps tested: 13.

Normal Candle-power: 10 and 16.

Name of Lamp	Number of Lamps.	Candle-power observed. l	Current in Ampères. c	E. M. F. in Volts. e	Resistance (hot) in Ohms. $r = \frac{e}{c}$	Electrical work in Watts. $e\,c$	Watts per Candle. $\frac{e\,c}{l}$	Candles per H. P. $\frac{736l}{e\,c}$	Coefficient of Reduction.	Remarks.
Greiner and Friedrichs.	1	15·5	·910	50·54	55·54	46·00	2·96	248		
	3	15·6	1·217	50·09	41·15	60·98	3·91	188	·73	
	4	16·9	·859	53·41	62·16	45·89	2·72	269		
	1	8·2	1·518	17·05	11·23	25·89	3·17	233		
	2	8·5	1·667	15·61	9·37	26·02	3·08	239		
	,,	10·2	1·717	16·18	9·42	27·79	2·47	269		
	20	16·5	·718	90·36	128·7	66·29	4·03	183		

5. Siemens Lamp.

Number of Lamps tested: 6.

Normal Candle-power: 16 (20?)

Siemens .	1	16·0	·983	93·94	95·60	92·32	5·76	128		
	,,	18·4	1·003	95·46	95·18	95·74	5·22	141	·76	
	2	15·3	·774	91·73	108·5	70·99	4·63	159		This lamp considerably differs from the remainder as regards the electrical work absorbed. Not known whether 16 or 20 candle lamp.
	,,	18·4	·801	94·12	117·5	75·36	4·09	180		
	,,	21·5	·828	96·75	116·8	80·10	3·72	198		
	3	16·4	·980	92·51	94·37	90·69	5·52	133		
	,,	20·6	1·020	95·42	93·54	97·34	4·73	156	.74	
	4	17·3	1·039	89·73	86·32	93·28	5·38	137		
	,,	21·7	1·092	93·33	85·48	101·9	4·70	157		
	5	16·3	1·023	90·06	88·08	92·09	5·67	130		
	,,	20·4	1·069	93·19	87·22	99·57	4·48	151		
	6	14·9	·966	92·51	95·76	89·36	5·99	123		
	,,	17·9	1·008	95·64	94·91	96·36	5·37	137		
	,,	23·3	1·056	99·09	93·80	104·7	4·50	164		

6. LANE-FOX LAMP.

Number of lamps tested: 10.

Normal Candle-power: 16.

Name of lamp.	Number of Lamps.	Candle-power observed. l	Current in Ampères. c	E. M. F. in Volts. e	Resistance (hot) in Ohms. $r = \frac{e}{c}$	Electrical work in Watts. $e\,c$	Watts per Candle. $\frac{e\,c}{l}$	Candles per H. P. $\frac{736l}{e\,c}$	Coefficient of Reduction.	Remarks.
Lane-Fox	3	16·7	·996	46·97	48·64	45·35	2·72	270		
	6	17·3	1·079	46·50	43·08	50·18	2·91	253		
	7	14·4	1·356	32·17	23·72	43·63	3·02	244		
	,,	20·4	1·445	34·50	23·87	49·86	2·45	301	·73	
	8	14·3	1·159	42·97	37·08	49·80	3·49	211		
	,,	18·8	1·223	45·43	37·16	55·54	2·96	248		
	9	15·2	·952	45·59	47·88	43·40	2·86	258		
	,,	19·1	·993	47·54	47·89	47·18	2·47	297		
	10	17·6	1·223	45·41	37·13	55·53	3·85	233		

7. LADIGUINE (JABLOCHKOFF) LAMP.

Number of lamps tested: 7.

Normal Candle-power: 20.

Ladiguine	1	17·1	1·339	33·03	24·67	44·22	2·58	285		
	,,	23·3	1·421	35·08	24·68	49·84	2·19	343		Raised to 325 candles.
	2	18·1	1·299	34·40	26·48	44·70	2·47	298		Raised to 450 candles.
	2'	16·7	1·313	34·61	26·36	45·44	2·72	271		
	,,	23·6	1·408	37·17	26·40	52·33	2·21	332		
	3	16·4	1·315	36·91	28·06	48·54	2·97	248	·77	
	4	16·7	1·378	36·00	28·46	54·04	3·25	227		
	5	19·2	1·312	39·21	29·88	51·46	2·69	274		
	20	20·7	1·407	37·20	29·45	52·40	2·53	291	·78	

8. MAXIM LAMP.

Number of lamps tested: 10.

Normal Candle-power: 16–18, 25 (30 ?).

Name of Lamp.	Number of Lamps.	Candle-power observed.	Current in Ampères.	E. M. F. in Volts.	Resistance (hot) in Ohms.	Electrical work in Watts.	Watts per Candle.	Candles per H. P.	Coefficient of Reduction.	Remarks.
		l	c	e	$r=\frac{e}{c}$	$e\,c$	$\frac{e\,c}{l}$	$\frac{736\,l}{e\,c}$		
Maxim .	1	15·9	1·346	56·02	41·63	75·39	4·74	155		
	,,	19·9	1·394	58·00	41·62	80·84	4·07	181		
	2	19·9	1·374	55·06	40·08	75·63	3·98	185	·56	
	3	16·8	1·353	55·36	40·92	74·91	4·46	165	·55	
	5	26·3	1·588	57·37	36·13	91·11	3·46	213		

9. MÜLLER LAMP.

Number of lamps tested; 10.

Normal Candle-power: 10 & 20.

Müller .	3	10·3	·755	55·74	73·82	42·09	4·11	179	·90	
	5	7·5	·736	48·33	65·65	35·58	4·74	155		
	,,	9·5	·769	49·69	64·58	38·23	4·04	182	·82	
	6	9·0	·801	47·56	59·41	38·07	4·25	173		
	,,	10·9	·832	48·99	58·88	40·77	3·73	198		
	11	18·8	·726	109·4	150·6	79·40	4·22	175		
	12	20·0	·818	112·5	137·5	91·99	4·60	160		

10. WOODHOUSE AND RAWSON.

Number of lamps tested: 7.

Normal Candle-power: 20.

Woodhouse & Rawson .	2	18·5	1·084	40·28	38·45	42·19	2·28	323		Lamps No. 1–5 were supplied by Messrs. Elphinstone & Vincent; No. 20. was sent by Messrs. Woodhouse & Rawson; No. 21 was personally submitted by Mr. Woodhouse on 28th Oct. as "latest lamp type."
	,,	22·7	1·097	42·03	38·30	46·11	2·03	363	·76	
	4	16·0	1·074	41·99	39·11	45·08	2·81	262		
	,,	20·6	1·128	43·97	38·97	49·60	2·41	306		
	5	20·9	1·233	43·82	35·63	54·03	2·59	284		
	20	16·8	·997	51·94	52·12	50·58	3·02	250		
	,,	20·1	1·033	53·72	52·02	55·47	2·75	267		
	21	20·1	·924	49·17	53·24	45·40	2·26	326		

11. BERNSTEIN LAMP.

Number of lamps tested: 5.

Normal Candle-power: 50 & 90.

Name of Lamp.	Number of Lamps.	Candle-power observed.	Current in Ampères.	E. M. F. in Volts.	Resistance (hot) in Ohms.	Electrical work in Watts.	Watts per Candle.	Candles per H. P.	Coefficient of Reduction.	Remarks.
		l	c	e	$r=\frac{e}{c}$	$e\,c$	$\frac{e\,c}{l}$	$\frac{736l}{e\,c}$		
Bernstein	2	59·4	5·391	28·39	5·265	153·0	2·58	286	·710	* Raised up to 350 candles. † Raised up to 600 candles.
	3	50·5	5·026	26·16	5·205	131·5	2·61	228		
	5*	54·5	5·289	27·02	5·109	142·9	2·62	281		
	1	83·3	8·272	35·71	4·317	295·4	3·55	207		
	4	88·3	8·360	35·13	4·202	293·7	3·33	221		
	†	96·5	8·540	35·69	4·179	304·8	3·16	233		

12. CRUTO LAMP.

Number of lamps tested: 3.

Normal Candle-power: 16.

Cruto	1	14·0	1·155	55·65	48·18	64·28	4·59	160	Not determined.	
	,,	18·2	1·213	58·00	47·82	70·35	3·87	190		
	2	15·7	·625	118·6	189·7	74·09	4·72	156		
	,,	18·8	·653	121·7	185·8	79·71	4·24	173		

General remarks on the construction, efficiency, and life of Glow Lamps.

The distinctive features of the different types of glow lamps which are in practical use now are naturally infinitely less striking than in the arc lamp. This latter employs a more or less complicated regulating mechanism and the constructive details of this mechanism give rise to an enormous variety of lamps. The glow lamp, which is fortunately restricted to the use of an incandescent filament placed in an exhausted globe, and which does not require any regulation mechanism, allows of difference only:—

1. *In the choice of the raw material from which the carbon filament is made.*
2. *In the treatment of the raw material before and after carbonization.*
3. *In the length of the filament and its cross section.*
4. *In the mode of connection of the filament with the current conductor, or the platinum wires respectively, which join it to the leads.*
5. *In the more or less perfect exhaustion of the lamp bulb.*

In considering these different points we wish to arrive at a conclusion, not that one type of existing lamp is superior to another, but what are the conditions to be fulfilled in order to obtain an efficient glow lamp of good durability.

(1.) All glow lamps, with the exception of the Cruto and Bernstein lamps, employ a vegetable fibre of some kind as raw material for preparing the filament. Edison considers the fibrous structure of bamboo advantageous for obtaining a tough filament of high mechanical resistance; while Weston, on the other hand, subjects the cotton fibre to a process which entirely deprives it of its structural character, and transforms it into amorphous cellulose, for which he likewise claims great toughness and mechanical resistance. We know what excellent results are obtained with the Swan filament, which consists of cotton, and we may safely draw the conclusion, that the nature of the raw material is of little consequence as long as it is of a thoroughly homogeneous character. The carbon is exposed to a series of deleterious influences, which are the more effective the less coherent the filament. Not to mention the shocks and concussions to which the lamps are subjected in transport, we find that, according to the mechanical theory of gases, the last remnants of atmospheric air, which are, even with the most careful exhaustion, left in the lamp-bulb, are set into rapid motion by the intense heat of the carbon; and thus this latter is exposed, so to say, to a continuous bombardment, which soon finds out any weak spot in its texture, and brings about the rupture of the filament. There are other influences at work tending to produce the same result, namely, the disintegrating effect of the current and the high temperature to which the filament is raised, and which show themselves in the projection of carbon particles on the interior of the lamp bulb (commonly called the blackening of the lamp bulb).

Under this head we have also to consider a fact observed by Edison, namely, that a continuous current passing through the carbon wastes it more rapidly on one side than on the other. For the explanation of this fact we must assume a sort of electrolytic process in a space which is not absolutely free from air, but only highly attenuated. If this observation is correct, and we have no reason for doubting its accuracy, it constitutes an additional reason for the importance of the uniformity of the filament. We have further to take into account the influence of the electric current on the structure of the carbon filament; and that such an influence is exercised has been proved by the molecular changes of a copper wire through which the currents of an alternating machine had been passed for some time.

Finally, the higher the temperature to which the carbon is exposed, the shorter its durability, and the more marked the deleterious effects on a filament of inferior compactness and uniformity.

(2.) The treatment of the filament of the Edison lamp before carbonization is a purely mechanical one; it consists in the removal of the silicious matter forming the outer covering of the strips of bamboo, and subsequently giving them the proper shape. The treatment of the vegetable fibre employed by Lane-Fox is a similar one, with additional boiling in caustic soda, to render the cleaning process more effective. The structural texture of the fibre is retained in these cases, and contributes to the solidity and firmness of the filament.

Swan, Weston, Woodhouse, and Rawson, and, as far as can be ascertained, Siemens and Halske, in their later types of lamps, proceed in the opposite direction; they have to deal with an artificially prepared vegetable fibre, such as cotton thread, and endeavour to deprive it of all its structural characteristics, changing the cellulose into an amorphous modification, and thus making the surface of the filament thoroughly homogeneous and uniform. It would almost appear as if Weston obtained the homogeneity of his filament at the expense of its durability; it has already been mentioned (v. p. 289) that, out of twenty 16-candle lamps tested by the Franklin Institute, only six survived the time of testing, namely, 1,065 hours; whilst out of ten 16-candle lamps of different current and E. M. F., seven survived the time of testing, which in this case was only 524 hours. It is more than probable that this inferior durability is due to the treatment of the filament. Swan treats the cotton thread which he uses for the preparation of the filaments with sulphuric acid, an operation analogous to the parchmentizing of paper, and which does not alter the chemical, but only the structural character of the fibre. Weston, on the other hand, uses nitric acid as well as sulphuric, and thereby converts the cellulose into gun-cotton, a compound in which the hydrogen of the cellulose has been more or less completely replaced by nitrogen tetroxide. It is true he afterwards reconverts the gun-cotton into cellulose by treating it with a reducing substance such as ammonium sulphide; but in all probability the fibre has been weakened by the treatment with nitric acid, and does not recover its original toughness and mechanical resistance.

The condition of the radiating surface is one of the main factors in the economy of a glow lamp, and the whole of the treatment subsequent to carbonization has for its aim *to endow that surface with the highest possible radiating capacity.*

This purpose is effected by the same method in the four lamp types mentioned above, as well as in the Bernstein, the Cruto, and the Puluj lamps; it is electrolytic deposition of carbon on the carbonized filament (in the Cruto lamp on platinum wire). This method, which is called the *flashing,* or *improving* of the filament, consists in exposing the latter either to a current of hydrocarbon gas rich in carbon, or to a liquid hydro-carbon of similar composition, rendering the filament incandescent by passing a current through it, and thus decomposing the hydrocarbon. A uniform layer or number of layers of carbon are thus deposited on the filament, contributing in no small degree to its compactness, homogeneity, and durability.

Another advantage of this method is that it allows of the accurate adjustment of the lamp for a certain definite resistance.

Messrs. Siemens and Halske, of Berlin, have made extensive tests to show in how far the efficiency and the life of the lamp is affected by the flashing of the filaments. They used for these comparative tests their own 16-candle lamp, in the manufacturing of which flashing is a leading feature, and the Edison 16-candle lamp, with a filament that had not been improved after carbonization. The lamps were worked during 800 hours, 9 hours per day, and the E. M. F. was kept, as near as could be constant by resistances inserted in the fine-wire circuit of the electro-magnet windings. The reason why two different types of lamps were used was that Messrs. Siemens and Halske had no experience with the construction and the properties of an unimproved carbon filament.

The following tables will show the results obtained.

TABLE I.

A. *Lamps with unimproved filaments.*

Burning hours.	E. M. F. in Volts.	Current in Ampères.	Light in Candles.	Candles per electric H.P.	Watts per Candle.	Remarks.
0	96	·710	19·9	215	3·4	After 50 hours 1 lamp burst.
100	96	·674	15·7	178	4·7	After 280 hours 1 lamp burst.
200	96	·656	14·3	167	4·4	After 650 hours 1 lamp burned thro'.
300	96	·654	13·8	160	4·5	The remaining 7 lamps survived.
400	96	·650	13·2	155·5	4·7	
500	96	·636	12·9	155	4·8	
600	96	·632	12·2	148	4·7	
700	96	·630	11·1	135	5·4	
800	96	·630	10·0	134	6·0	

B. *Lamps with improved filaments.*

Burning Hours.	E. M. F. in Volts.	Current in Ampères.	Light in Candles.	Candles per electric H.P.	Watts per Candle.	Remarks.
0	96	·550	17·5	244	3·0	The 10 lamps survived.
100	96	·550	17·5	244	3·0	
200	96	·550	17·5	244	3·0	
300	96	·544	17·0	239	3·1	
400	96	·544	16·5	232	3·2	
500	96	·540	15·9	225	3·3	
600	96	·535	15·05	215	3·4	
700	96	·528	14·5	213	3·5	
800	96	·528	14·5	213	3·5	

TABLE II.

A. *Lamps with unimproved filaments.*

Burning Hours.	E. M. F. in Volts.	Current in Ampères.	Light in Candles.	Candles per electric H.P.	Watts per Candle.	Remarks.
0	100	·687	24·25	259	2·8	After 500 hours 1 lamp burned thro'. The others survived.
100	100	·666	15·7	173	4·2	
200	100	·666	15·3	169	5·0	
300	100	·664	15·2	167	4·4	
400	100	·653	14·7	165	4·5	
500	100	·640	13·7	157	4·7	
600	100	·634	13·3	154	4·8	
700	100	·630	13·1	153	4·9	
800	100	·620	12·5	148	5·0	

B. *Lamps with improved filaments.*

Burning Hours.	E. M. F. in Volts.	Current in Ampères.	Light in Candles.	Candles per electric H.P.	Watts per Candle.	Remarks.
0	100	·552	25·0	333	2·2	All 10 lamps survived.
100	100	·550	22·5	300	2·4	
200	100	·550	22·0	290	2·5	
300	100	·548	21·0	282	2·6	
400	100	·547	20·0	270	2·7	
500	100	·545	18·6	251	2·9	
600	100	·545	17·1	231	3·2	
700	100	·540	16·0	218	3·4	
800	100	·532	15·3	210	3·4	

It will be seen from Table I. A, that the difference of illuminating power amounted to as many as 8·9 candles at the end of the test, that the lamps gave 13·58 candles on the average, a mean efficiency of 159·1 candles per H.P. At the end of the test the efficiency was only 62·3 per cent. of the initial one, the illuminating power had fallen to 55·3 per cent. of the original value, and the resistance (when hot) had increased by 12·7 per cent.

On referring to Table I. B, we find that the difference in illuminating power only amounted to 3 candles, that the average light was 16·24 candles per lamp, and the mean efficiency 203·1 candles per H.P. The efficiency had fallen to 87·3 per cent., and the illuminating power to 82·9 per cent. of the original value. The increase of resistance was 4·2 per cent.

Tables II. A and B, show the results of tests made with a higher initial E. M. F., and we find in Table II. A a decrease of as many as 57·1 per cent. in the efficiency, and of 51·5 per cent. in the illuminating power; the greatest difference in light was 11·75 candles per lamp, the mean illuminating power 14·91 candles, and mean efficiency 167·7 candles per H.P.; the increase of resistance was 10·8 per cent.

On comparing these results with those of Table I. A, the former will be found more favourable, in spite of the somewhat lower mean efficiency, in so far as the decrease of light was not only smaller but also much steadier.

In Table II. B, the greatest difference in illuminating power is 9·7 candles, the increase of resistance 3·8 per cent., the mean illuminating power was 19·67 candles, the mean efficiency 264·1 candles per electrical H.P. After 800 hours the mean efficiency had fallen to 63·1 per cent., and the illuminating power to 61·2 per cent. of the initial value.

Diagram to Table I.

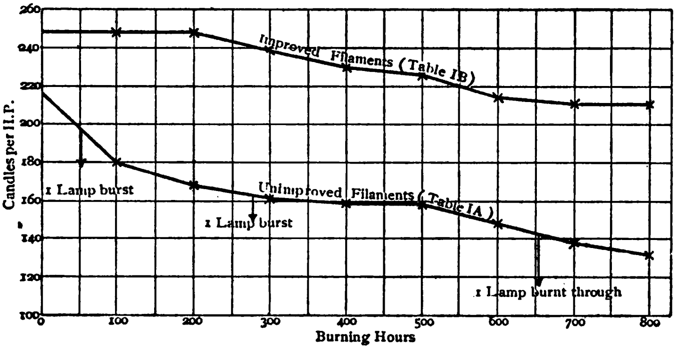
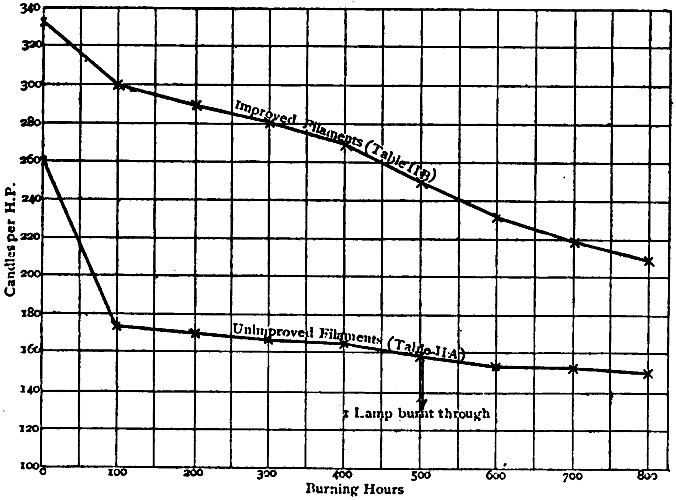


Diagram to Table II.



In order clearly to show the difference in the results obtained with the two kinds of filaments, we give some diagrams taken from the *Electrotechnische Zeitschrift*, November and December, 1885.

In the diagrams the burning hours are taken as abscissæ, while the efficiencies, or number of candles per electrical H.P., are taken as ordinates.

It will be seen that the curves show a marked difference, especially with regard to the efficiency during the earlier period of working, which falls very rapidly with unimproved carbons, whilst it remains much more constant on using flashed filaments.

On comparing curves I. B and II. B (flashed filaments) we find, in the first instance, that the latter, with an initial efficiency of 340 candles per electrical H.P., shows a better mean efficiency than curve I. B, where the efficiency begins with 244 candles per H.P. The mean efficiencies are as 264·1 : 230·1, or as 100 : 87·1.

Curve I. B, on the other hand, shows much greater constancy and uniformity. Quite apart from the fact, that lamps constructed according to curve I. B would last much longer than those constructed according to II. B, the latter do not recommend themselves for practical use, because their illuminating power falls to 61 per cent. of the initial value. It is, however, a remarkable fact, that for the same burning hours (800) the resistance increases less in the lamps which are heated to a higher temperature. From this follows that the blackening of the lamp bulb has a much larger share in the diminution of illuminating power in the latter case than in the former. In either case, however, the main reason of this diminution lies in the increase of resistance. Curves I. A and II. A are especially remarkable from their strikingly irregular path. In spite of the very different initial values of the efficiencies, an almost complete approximation was already reached after 100 burning hours. The efficiency in both cases after 100 hours was a little less than 180 candles per electrical H.P., whilst the respective initial values were 260 and 220 candles.

For better enlightenment on this point, further tests with these lamps at a still higher temperature and higher initial efficiency were made.

In this case too ten lamps were used, but as it was mainly a question of studying the behaviour of the lamps during the early period of working, the tests were abandoned after 100 hours.

The two following tables show the results obtained.

TABLE III.

Lamps with unimproved filaments.

Burning hours.	E. M. F. in Volts.	Current in Ampères.	Light in Candles.	Candles per electric H.P.	Watts per Candle.	Remarks.
0	115	·863	44·2	328	2·2	After 11 hours 30 min. 1 lamp burned through.
10	115	·817	38·5	303	2·5	
20	115	·808	33·5	265	2·8	
30	115	·806	31·5	251	2·9	After 22 hours 1 lamp burned through.
40	115	·806	29·1	231	3·2	
50	115	·806	26·4	209	3·5	After 26 hours 1 lamp burned through.
60	115	·806	26·0	206	3·6	
70	115	·806	25·3	201	3·7	After 85 hours 1 lamp burned through.
80	115	·801	24·1	192	3·8	
90	115	·793	22·8	181	4·0	The remaining 6 lamps survived.
100	115	·795	20·7	175	4·4	

TABLE IV.

Lamps with unimproved filaments.

Burning hours.	E. M. F. in Volts.	Current in Ampères.	Light in Candles.	Candles per electric H.P.	Watts per Candle.	Remarks.
0	123	·932	68·4	438	1·7	After 6 hrs. 12 min. 1 lamp burned through.
1	123	·929	64·6	412	1·8	
2	123	·929	60·0	386	1·9	After 8 hours 6 min. 1 lamp burned through.
3	123	·930	56·9	360	2·0	
4	123	·924	49·9	323	2·3	After 8 hrs. 15 min. 1 lamp burned through.
5	123	·922	45·1	293	2·5	
6	123	·924	42·8	277	2·7	After 8 hrs. 20 min. 1 lamp burned through.
7	123	·910	39·9	262	2·8	
8	123	·907	38·9	257	2·9	After 12 hrs. 12 min. 1 lamp burned through.
9	123	·885	36·5	256	3·0	
10	123	·880	36·3	247	3·0	After 13 hrs. 4 min. 1 lamp burned through.
11	123	·880	34·65	235	3·1	
12	123	·880	33·7	229	3·2	After 13 hours all 6 lamps burned through.
13	123	·880	31·9	222	3·4	

The path of curve III. shows that in this case too the efficiency after 100 hours had fallen to the same amount as in curves I. A and II. A.

The last test with six lamps was made with a still higher initial efficiency, and is recorded in Table IV. The life of the lamps, corresponding to the higher temperature of the filament, was very short, and all six lamps were burnt through after 13 hours. The measurements in this case were taken hourly.

The path of curve IV. shows such a large diminution of efficiency, even during the few hours of testing, that it appears probable that the efficiency even after 100 hours would not have been greater, provided the lamps had lasted so long.

If we now sum up the results obtained with unimproved filaments, we must come to the conclusion, that there is no object in quoting for the lamps a higher initial efficiency than about 170 candles per electrical horse-power. Calculations made on the basis of the price of the lamps, and which pretend to determine the most appropriate values of life and efficiency on that basis, appear to be of no value whatever.

Diagram to Table III.

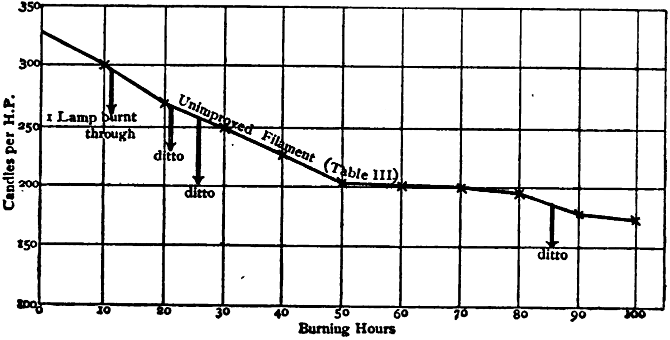
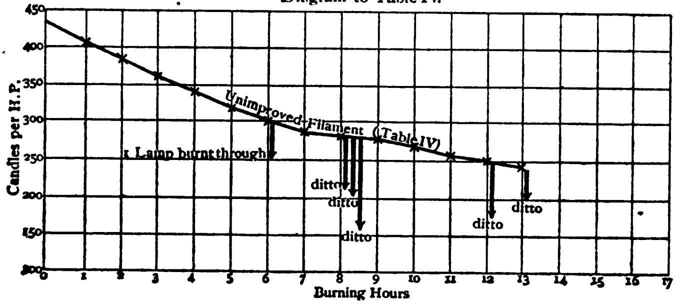


Diagram to Table IV.



Curves B show that with flashed filaments, for an equal expenditure of energy, one-third more light can be produced than with the unimproved filament; or, in other words, that one-third more 16*-candle lamps with unimproved filament* *would be required to produce the same quantity of light, and further, that the flashed lamps possess in a very high degree the property of maintaining their efficiency during the customary working hours, and also of preserving a very uniform light.*

We may here make the remark, that lamps have lately been brought into the market which claim an efficiency of 2½ or even 2¼ watts per candle. Sixteen-candle lamps of this kind may in all probability be represented by curve II. B. If we express the efficiency of this curve in watts per candle, we get for the initial efficiency 2·2 watts per candle, and for the mean efficiency 2·8 watts per candle; whilst for curve I. B (the normal curve of the Siemens and Halske lamp) we get 3·1 and 3·3 watts per candle respectively.

We may finally conclude from this, that it is not advisable to burn the 16-*candle lamp at less than* 3 *watts per candle.*

This remark is purposely limited to the 16-candle lamp, and all those lamps which have even a smaller cross section. It has been found that the method of flashing is even more advantageous for thicker filament, and that the results obtained with them are even more favourable.

(3.) In discussing the question of length and cross section of the filament, we must be guided by the following considerations: Carbon is a conductor of electricity, and is heated by the passage of an electric current; a strong current will raise the temperature of carbon to a certain degree of white heat, without destroying it. If this degree of heating is reached, and has to be preserved constant, a continuous flow of current during unit of time is required, to which corresponds a definite quantity of radiation during the same interval of time. The work performed by the current is thus $ec = \frac{e^2}{r} = c^2 r$, where e is the difference of potential at the two extremities of the carbon, c the working current, and r the resistance of the carbon. The radiation corresponding to this work, at a certain temperature, is proportional to the size of the carbon surface. If l is the length of carbon and d its diameter (a circular cross section being assumed), the surface is proportional to $l\,d$. For a state of equilibrium between current work and radiation we therefore have (leaving the constants out of the calculation) $c\,e = l\,d$.

It is clear that with the above limitations the product $l\,d$ also gives a measurement for that part of the total radiation which presents itself in the form of light-giving heat rays or light, in opposition to, or we should rather say, to the exclusion of the dark and chemical heat rays.

To a definite quantity of light, or a definite total radiation, correspond therefore definite dimensions of the surface and a definite quantity of current work. This latter remains constant when the two factors of the product $e\,c$ vary in such a way that the product itself remains constant. The larger e becomes, the smaller must c be. Currents of the most different kind, therefore, will perform the same amount of work; weak currents of high tension, and strong currents of low tension. The resistance r too varies accordingly, as will be seen from $\frac{e^2}{r} = c^2 r = \text{const.}$ From $e\,c = l\,d = \text{const.}$ follows: $\frac{e}{l} = \frac{d}{c}$, from which will be seen that the factors l and d of the constant product $l\,d$ vary in accordance with the variations of e and c.

We can therefore for the production of a definite quantity of light (a surface of a definite kind and equal conditions of temperature and of material being given) employ carbons of the most varied forms. The glow lamps may therefore be distinguished according to the form of the filament; lamps with a long and thin filament and correspondingly high E. M. F., and lamps with a short and thick filament and correspondingly large current.

A characteristic difference between the two kinds of lamps lies in the difference of cross section, whose size decreases with the increase of E. M. F. There can be no doubt that, *cæteris paribus*, a larger diameter constitutes a considerable advantage, namely, greater solidity of the carbon and longer life of the lamp.

All the considerations which ought to guide us in the choice of the raw material for the preparation of the filament, and which have been stated on p. 302, apply with equal force to the question of length and cross section. A thicker carbon thread will be more capable of resisting the shocks and concussions as well as the high temperature to which it is in turn exposed than a thin one; and this latter circumstance is of importance, not only from an economical but also from an æsthetical point of view, because the more intense the heating of the filament, the whiter is the light obtained.

It therefore follows that lamps of low tension present the advantage over lamps of high E. M. F., that for a definite illuminating power their filaments are thicker, and their durability and heating capacity correspondingly greater.

Against this one advantage of lamps of large current we must, however, put the serious drawback of the expensiveness of the leads. (This of course applies to parallel connection, which seems to be the most rational method for incandescent lighting; series connection for a larger number of low-tension lamps would necessitate in the first place a separate cut-out for each individual lamp, and secondly would bring into the house a current of a high potential which is absolutely forbidden by existing regulations.) The larger e is in the product $e\ c$, the larger is the mass of copper required for the leads. To guard against risk of fire the leads must be of such dimensions that they are not heated above a certain limit by the working current. The ratio between current and dimension of leads is expressed by $c = d$, constants being omitted. If the leads have a rectangular instead of a circular cross section, we have $u = c$ (where u is the circumference of the section). The circumference of the section therefore, and not its size, is the decisive factor; but the mass of copper used in the leads depends on the size of the cross section; and in order to secure the greatest economy of copper, the cross section must be of the smallest possible size for a given circumference. A rectangular form of the section is therefore preferable to a circular one, and it is a decided advantage that the leads should consist of a number of parallel thin wires, and not of one single stout wire. From $d = c$ will be seen how unfavourable the conditions are for lamps of large current, because a current of double strength requires four times the quantity of wire.

Another consideration as well leads to the conclusion, that the diameter of the conductor must be directly proportional to the current it conveys ($d = c$). In an installation of glow lamps a certain part of the energy of the current will be wasted in the leads; the resistance of the leads ought, therefore, to be made as small as possible, so as to minimize the waste of energy. In order, however, to limit the mass of copper, practice allows 10 per cent. of the energy expended in the lamps for the conductors, so that the resistance of the leads must be 10 per cent. of the resistance of the lamps.

The drawback of expensiveness connected with the employment of lamps of low tension can be partly overcome by having recourse to certain combinations of parallel and series connection (multiple series or compound parallel), and we often find such like arrangements with lamps of large current, even with the Swan lamps. Two or more Swan lamps, for instance, are joined in series, and are arranged in parallel with a number of other lamps similarly connected; or the installation is made to consist of two or three large groups joined in series, each of which groups consists of an equal number of lamps arranged in parallel. The former arrangement has the disadvantage, that the extinction of one lamp brings about the extinction of those lamps which are contained in the same series. In case of the latter arrangement (although the extinction of one lamp is not accompanied by that of others), we have to take into consideration that it is the same current which flows through the individual groups, each of which must be in a position to dispose of this current; now, on the extinction of several lamps, the current would be divided over a smaller number of lamps, and these lamps would be overworked.

An arrangement of this kind would be open to objections unless the lamps of each group were of a certain number, and unless the installation comprised several circuits independent of one another. It can only work successfully where all the lamps in circuit burn at the same time (it works very well at the Savoy Theatre, for instance), but it is not admissible where an individual burning of single lamps is required, and where a smaller or larger number of lamps have to be switched on or off, as the case may require; and still less so (even if all the lamps burn simultaneously) where lamps of different illuminating power and consequently of different current strength are employed.

In this latter case, we can of course again connect the lamps in series or arrange them in parallel; in other words, we can work them either with a constant E. M. F. or with a constant current. To fulfil the former condition, it has been found that $\frac{l^2}{d}$ must be constant (l length of filament and d its diameter), whilst for the latter arrangement d must be kept constant.*

In the case of a series connection being adopted, the lamp filaments can therefore only vary in length, while their diameter must be the same, the illuminating power being proportional to the length of the filament. This arrangement however has no practical value, since the E. M. F. would, for a large number of lamps connected in series, become too high (each 10-candle lamp requiring from 30 to 40 volts). If, on the other hand, we adopt the parallel arrangement, the lamps may vary both in length and diameter of the filament, as long as the condition $\frac{l^2}{d} = \text{const.}$ is fulfilled.

We have now to decide the question as to the most convenient E. M. F. to be given to a system of lamps comprising the most varied types. This E. M. F. will be chosen as high as possible. If we assume again equal material and equal temperature of the filament, a surface of definite dimensions will correspond to an illuminating power, say of 10 candles (lamps of lower candle-power will hardly be required for domestic purposes). If we now have a carbon of the smallest possible diameter consistent with the requirements of durability, we shall have to make it of sufficient length to obtain a surface corresponding to an illuminating power of 10 candles. That current having a sufficiently high E. M. F. to bring up the illuminating power of the lamp containing a filament of the said kind to 10 candles will be the desired current. The size of the lamp will be dependent in the first instance on the illuminating power to be apportioned to the smallest type of the system, and secondly on the limit to which the diameter of the filament can be reduced without injuring its durability.

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* For details of method leading to this result we refer the reader to *Electrotechnische Zeitschrift*, March, 1883, p. 111.

If the efficiency of a transmission of energy is to be kept constant for varying distance, $\frac{e^2}{r}$ must remain constant. The same holds good for the efficiency of a light installation. In the latter case $\frac{e^2}{r}$ represents the work expended in the lamp for producing a certain luminous intensity. The resistance of the filament must increase, in the same measure as the resistance of the leads, if the ratio between the energy wasted in the conductors and the total energy is to remain the same. We therefore get the requisite E. M. F. from $\frac{e^2}{r} = \text{const.}$ (since the illuminating power, or efficiency of the lamps, must not be altered), and in the same way the new current from $e^2\ r = \text{const.}$ The larger r and e are chosen, the thinner the filament must be made; and since the extreme limit in this direction is soon reached, the impossibility of making the filament too thin constitutes a practical limit of the proposition, that the efficiency is independent of the distance. Whilst in the case of glow lamps the limits of this proposition are to be sought in the limited capacity of enlargement of *r*, the obstacle in the transmission of force lies in *e*, and in the difficulty to obtain an efficient insulation of the wires of the dynamo.

Wilhelm Siemens considers that, with the present material and manufacturing methods, it will be hardly safe to exceed 100 to 110 volts for 10-candle lamps, the filament in this case being already very thin, about ·15 mm. (·0265 inch). The E. M. F. of Messrs. Siemens and Halske's glow lamps has been fixed at 105 volts, a choice which is duly founded on the considerations given above, and which is (and not accidentally so) in close accordance with that of the Edison lamp. That Edison has from the very outset, when constructing his first glow lamp, discerned the fitness of a high E. M. F. cannot be too highly commended. The dimensions of the filaments of lamps of 105 volts will best be seen from the following table, representing three types of lamps manufactured by Siemens and Halske of 10, 16 and 25 candles respectively.

Candles.	Diameter in millimetres.	Length in millimetres.	Cross section in sq. millimetres.	Surface in sq. millimetres.
10	·15	110	·017	50
16	·20	125	·031	75
25	·27	145	·056	120

The light of these lamps, although differing in intensity, shows the same tint, and their surface is nearly proportional to their illuminating power. There is no difficulty in constructing lamps of this kind with a higher illuminating power; Siemens and Halske have made lamps of 100 volts and 130 candles for street illumination.

It will be seen from the above table that the cross section of lamps of different candle-power increases much more rapidly than the illuminating power and the surface, and this means, as has been already stated, an increase of durability and of life of the lamp. Hence it follows that in an installation employing lamps of different candle-power the smaller lamps are subject to a much greater strain than the larger ones, and that it is therefore advisable to use lamps of higher candle-power wherever possible.

It further follows that the advantage of lamps of low tension, which consists in a larger diameter and consequently greater durability, in so far disappears in lamps of higher tension as their candle-power is increased. So, for instance, the diameter of the Swan lamp is ·25 mm., while that of Siemens and Halske's 25-candle lamp is already ·27 mm. This consideration is of special importance for the illumination of large areas.

Under this head we have finally to consider which is the most convenient form of section of the filament. This form is not without influence on the ratio of the two factors *e* and *c*. Let us take two carbon filaments of the same length and the same cross section, one having a rectangular, and the other a circular form. The rectangular carbon will then have a larger surface than the round one, while the stability of the two filaments, on account of their equal section, will be the same; at the same temperature the radiation of the square carbon will be larger, since the amount of radiation is proportional to the surface. In order to obtain equal radiation, the round carbon is lengthened, leaving its section unaltered.

We have now two lamps of equal surface and candle-power, and also, on account of the equal cross section, of equal durability, and *ec* is also equal in both cases. But the round carbon being longer, has a higher resistance than the square one, and therefore *e* will be larger for the round carbon, and *c* for the square one; the round shape is consequently preferable to the square form, because a higher E. M. F. is obtained with the same expenditure of work, and the durability of the lamp remains the same. We may sum up in saying that that form of section is the best which gives to the section the smallest circumference. For the leads this proposition has to be reversed, as we have shown above.

(4.) A most important advance has been made by Messrs. Siemens and Halske, in the mode of connection of the filament and the platinum wires which join it to the conductors. In all types of lamps the connection was made by means of a cement, consisting of various substances according to the kind of lamp; for instance, plumbago and Indian ink, sugar and graphite, etc. The extremities of the filament were first of all thickened for this purpose, then joined to the platinum wires, and the cement put on with a brush; the combination of filament and platinum wires had to be baked in a small muffle.

Quite apart from the fact, that these operations are of a complicated nature, and therefore difficult and involving great loss of time, the thickened jointures enclosed a comparatively large quantity of air, which could not be got rid of by exhaustion; the consequence was, as we have ourselves repeatedly observed, that the expansion of the air enclosed in the thickened carbon ruptured the connection between the carbon and the wire, and further naturally shortened the life of the lamp.

Messrs. Siemens and Halske have patented a most simple method of connection, which consists in forming the flattened extremities of the platinum wires into a small helix, inserting the filament therein, and nickel or copper-plating the jointure; care being taken that the last windings of the helix which lie nearest to the incandescent carbon remain free from galvanic deposit, and thus protecting the platinum itself against incandescence and consequent volatilisation. A similar arrangement has already been described (p. 293) in the Cruto lamp. The extremities of the platinum wires are there formed into thin tubes, and a firm connection between the carbon filament and the platinum wire is obtained by electrolytically deposited carbon.

(5.) The exhaustion of the lamp bulb is a most important feature in the manufacturing of glow lamps. The life of the lamp is to a great extent dependent upon the success of this operation, and this success is naturally dependent on the implement used for this purpose. From personal experience we have found that a pump without stopcocks, such as the Lane-Fox pump described on p. 286, gives infinitely better results than pumps with several stopcocks which require greasing, like the Sprengel or Geissler pumps; and not only is the result more satisfactory, but the time of exhaustion is also much shorter.

A new method for exhausting the bulb, by which the same bulb can be used again after the destruction of the filament, has lately been patented by Mr. Wellstein, of Berlin. The platinum wires traverse a sort of stopper with an elastic band, and the stopper is upon exhaustion pressed air-tight against the neck of the bulb. It remains to be seen if this arrangement answers the purpose; if it does, it will considerably reduce the price of the glow lamp.

Having now fully discussed the question of construction of glow lamps, we have to add a few words as to their efficiency and durability.

We have already, in describing the individual lamps in use at the present time, given, as far as was possible from the information at our command, various figures and data as to their efficiency. It is certainly a matter of great satisfaction that, on comparing the results obtained with glow lamps, say three years ago, with the results of recent tests, the efficiency shows a marked and decided advance. To put it roughly, we may say that, while the efficiency formerly varied between 100 and 200 candles per horse-power, it is now between 150 and 250 candles per horse-power. This advance is entirely due to improved methods of manufacturing, which have been fully explained in the preceding pages; and if we take the latest types of the Swan and the Siemens and Halske lamps as examples, we find that their efficiency varies—for the Swan lamps of different candle-power, between 200 and 240 candles per horse-power; for the Siemens and Halske lamps of different candle-power, between 210 and 270 candles per horse-power. This efficiency, it must be remarked at once, is obtained under conditions which do not endanger the durability of the lamp. In the case of the Siemens and Halske lamp, for instance, it was obtained with lamps which burned for 800 hours; and only those tests are of any value which give the efficiency of a lamp together with the number of burning hours established by protracted experiments. Anybody who has had anything to do with glow lamps knows with what caution statements as to their efficiency and life have to be received. All we can say about it is that it resolves itself simply into a question of expediency and economy, whether it is desirable to exact from a lamp brilliant light or a long life. We have a very simple means at our command to prolong the life of lamps, namely, by lowering the temperature of the filament. It is, as we have said, entirely a question of expense; we have to take into consideration the prime cost of the lamps, and at the same time the cost of the energy expended in the lamps; and with the present state of affairs (considering the expensive methods for generating electricity) it is certainly not less important or less economical to reduce as much as possible the expenditure of energy in the lamp than to prolong their life beyond 800 or 1000 hours. Comparative calculations have been made in this direction by Profs. Ayrton, Perry and Dietrich, Dr. Fleming, and Mons. Szavardy; we need not enter here upon details concerning them, because they have not yet led to a definite result. Prof. Dietrich, for instance, does not take into account the gradual loss of illuminating power during working, a loss which in the Siemens-Halske lamp amounts to 3 candles per lamp for 800 burning hours, and to as many as 9 candles for the Edison lamp. Dr. Fleming* has found that the life of the Edison 16-candle 105-volts lamp varies inversely as the twenty-fifth power, roughly, of the electromotive force, and that the most favourable conditions of working from an economical point of view are when the expenditure for the renewal of lamps is 17·4 per cent. of the total expenditure. Calculations made by the Edison Company in America show that this proportion is 16 per cent., a result which very nearly agrees with Dr. Fleming's statement.

It has been stated, on p. 273, that the Electrical Exhibitions at Paris, Vienna, and Munich have not furnished us with sufficiently reliable information to pronounce a general opinion on the efficiency of glow lamps, and the reason simply is that the tests which were made at those places did not take into account that most important factor of efficiency, the life of the lamps. But, although the tests were not conclusive in this respect, it must be acknowledged that the Scientific Commission of the Munich Exhibition have increased the repertory of electrical science by a number of important facts.

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* *Electrician*, March 21, 1885, p. 401.

They found that, within certain limits (limits of variation of resistance), the candle-power of a glow lamp increased *as the third power of the electrical work expended in the lamp.* Now the electrical work is proportional to the square of the current, and the candle-power ought therefore to increase as the fifth power of the current; experiments, however, made by Mr. Preece*) have shown that *the candle power increases as the sixth power of the current;* and this is explained by the fact, that the resistance of the filament varies inversely with the current.

The commission further determined for the different lamps the mean spherical illuminating power produced by unit of electrical work, and found for the

Edison A	·0000376
Edison B	·0001106
Small Swan	·0000848
Large Swan	·0000096
Maxim	·0000148
Siemens	·0000225
Cruto	·0000250

These constants enable us to find the efficiency of a lamp in candles per horse-power, without previous photometric measurements, in the following way:

Let us take the Edison B. lamp, tested at Munich, which gave 11·69 candles with a current of 55·78 volts, and ·825 ampères (46·02 watts) or

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* Mr. Preece's paper, read before the British Association, at Aberdeen, 1885.

$$\frac{11 \cdot 69 \times 746}{55 \cdot 78 \times \cdot 825} = 185 \text{ candles}$$

for one horse-power. By means of the constant No. 2 given above we find the candle-power: $L = (c\,e)^3 \times \cdot 0001106$, where c is the current in ampères, and e E. M. F. in volts $L = (46 \cdot 02)^3 \times \cdot 0001106 = 10 \cdot 779$, or efficiency in candles per horse-power (E)

$$E = \frac{10 \cdot 779 \times 746}{46 \cdot 02} = 175 \text{ candles.}$$

The Commission also found that *the intensity of light radiated by a glow lamp in the horizontal plane and in different directions is dependent on the form of cross section of the filament; a circular cross section produces an equal intensity of light in all directions of the horizontal plane,* and further:—

The distribution of the light radiated by a glow lamp in different directions is dependent on the projection of the filament in the said direction.

The economical working of a glow lamp, according to Wilhelm Siemens,* depends entirely in the first instance on the radiating capacity of the surface of the filament, and secondly on the temperature to which the filament is heated. The latest types of flashed filament lamps give, according to the temperature at which they are worked, from 200 to 250 candles per electrical horse-power. The efficiency of the arc lamp may be taken as 1,500 candles per electrical horse-power, and the efficiency of the glow lamp is therefore to the efficiency of the arc lamp as 1 : 6. Now, allowing even for probable improvements of the glow lamp—and there can be very little doubt that improvements will be made in the filament, which will enable it to support a higher temperature, and also in the formation of surfaces of higher radiating capacity—it is very doubtful that the glow lamp can ever enter into serious competition with the arc lamp, where it is a question to produce a large quantity of light at moderate cost. The proper sphere of activity for the glow lamp begins where that of the arc lamp ends; it is destined to furnish such smaller quantities of light which the arc lamp cannot give, and which are required for domestic purposes.

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* *Electrotechnische Zeitschrift*, p. 115. March, 1883.

PART IV.

THE APPLICATIONS OF ELECTRIC LIGHTING.

THE practical applications of the electric light daily increase in number and importance. Within a short space of time that illuminating agent has become an almost indispensable helpmate to the scientific man, the artist, the engineer, and the man of business. The applications are in fact too numerous to be treated here in detail; we must confine ourselves to a short account of those amongst them which, either from a scientific or practical point of view, present the greatest interest. Before proceeding to the description of the applications themselves, we have to say a few words of the sources of electricity with regard to their application for electric lighting.

Liquid batteries and thermo-electric batteries need not be considered here; they are, so to say, out of the running; and though we read from time to time of a wonderful new battery destined to beat the dynamo out of the field, we may safely say that, as long as such expensive materials as zinc and nitric acid are employed in a battery, the dynamo need not fear its competition.

Secondary Batteries.

The description of this class of apparatus does not come within the range of this book, we have only to consider its fitness for the purposes of lighting.

Although the large expectations which were raised on the first introduction of the Faure battery into this country have not been realised, the secondary battery has obtained a firm footing for special adaptations. We will say at once that, as long as they retain their present prices and conditions, they will hardly be available by themselves for large installations; but they render excellent service as reserve apparatus, in the case of partial extinctions or other accidents, for temporary lighting (garden parties, concerts, baths, etc.), and last, but not least, they are almost indispensable for isolated and domestic light installations. One of the great advantages of gas is, that we can turn on or off any number of lights at any time during the day and also the night; and had we to give up this great convenience on adopting electric light instead of gas, we feel sure that the glow lamp would never find its way into the drawing-room. To obtain this indispensable condition we cannot feed our lamps directly from the dynamo unless we keep the driving engine going night and day. This, quite apart from the trouble of necessary attention and supervision, would add enormously to the expenses of working; and therefore, as long as we have no central stations supplying current, as gas companies do gas, we must have an arrangement which allows us to turn on or off any number of glow lamps at any time, and such an arrangement is the secondary battery.

It will be of interest to give Mr. Preece's experience in the charging and the efficiency of secondary batteries, taken from his paper read before the Royal Society.

Mr. Preece lights his house by electricity; he uses 24 Planté cells, which we need not describe here, and charges them twice a week, putting in at each charge about 120 ampère hours. During each charge observations are made every hour, and sometimes every half hour; (1) of current strength, (2) of the electromotive force, and (3) of the density of one or more of the cells. The relation of these three quantities shows the condition of the charge. These observations indicated that after four hours continuous charging the battery was full; for the density, the E. M. F. and the strength of current became constant. When its magnitude reaches its constant, bubbles of gas are freely given off, and energy is wasted. The counter electromotive force of the fully formed cells manifests itself in a higher resistance opposing the charging current, and increasing the proportion of the current through the shunt of the dynamo. The changes in the E. M. F. as given by the voltmeter are sufficient alone to indicate the progress and completion of the charge. One great drawback to the economical working of secondary batteries is the leakage to which they are more or less subject, and which in some cases amount to several per cent. of the charge during the period of discharge. It is clearly proved by Mr. Preece's observations, extending over a period of more than twelve months, that this leakage can be prevented; and as this leakage is one of the main causes for making the use of secondary batteries expensive, the result obtained by Mr. Preece is most important. The current used to escape over the edges of the box through creeping and through the formation of moisture from the spray of the solution, when bubbles of gas formed in the liquid and burst on the surface. This was quite cured by placing each box on three white porcelain supports standing in cups half filled with resin oil, and the insulation may be said to be practically perfect.

The capacity of these batteries seems to improve with age, and Mr. Preece has up to the present observed no sign of decay or deterioration. He puts in about 240 and takes out about 200 ampère hours weekly, and has not noticed any change or fall in the electromotive force. Occasionally one plate of a group becomes inactive from undue local action, or from bad connection (shown by the colour). This plate is then removed, and put in what Mr. Preece calls a "hospital cell," where it is brought into order either by a greater density of current or by reversal.

Reversing has a very beneficial action on a cell; it not only improves its capacity, but it removes any cause of irregular working. It is advisable to do this periodically. Mr. Preece has two extra cells, which enables him to have two cells always under reversal by means of the charging current. It takes from 1,000 to 1,200 ampère hours to reverse a cell, so that it takes about a year to reverse the whole battery.

For charging the secondary batteries a small Gramme dynamo of 42 volts and 36 ampères, manufactured by Ellwell and Parker, of Wolverhampton, is used, and driven by a two horse-power Clerk gas engine. The secondary cells are connected directly to the house by means of copper mains insulated with india-rubber, the same kind of wire, but smaller, being used everywhere for mains and sub-mains. The switch and lamp leads are of No. 18 copper wire, insulated with gutta percha, having a double layer of cotton braided together into a neat twine, the whole being well paraffined. The fittings of the bracket lamps are provided with Sir W. Thomson's switch, and there are a number of portable lamps for use in the drawing-room and the library. Various lamps have been tried, but none over 10 candles are used now. Little Miss Preece's doll's house must not be forgotten, which is lit by four tiny glow lamps fed from the main current. It was formerly supplied by a separate battery, but Mr. Preece has fixed a resistance underneath the doll's house, and the lamps are now switched on and off like all the other lamps in the house.

Each room in the house—we mean "the" house, not the doll's—has its own circuit, controlled by a switch in the central hall and protected by a safety cutout. Every fixed lamp has a switch to put it in or out of circuit at will. The engine room has a Cardew voltmeter, to determine the electrical pressure and condition of batteries; a galvanometer is also fixed below the main switch in the hall, to see what number of lamps are burning in the house, to detect any that may be left improperly turned on, and to test the condition of the circuits.

A Ferranti meter has lately been introduced into the charging and discharging circuit, which records exactly the quantity of electricity passed through the batteries and that passed through the lamps.

This instrument consists of a small phospor-bronze vane immersed in a bath of mercury, through which the current flows radially, fixed in a magnetic field. The mercury rotates and carries with it the vane. The rate of rotation varies directly with the strength of current, and the number of rotations are recorded by a counter which can be read off directly.

Mr. Preece states that his electric light costs him about £50 a year for gas, wages, oil and lamps.

There can be no question that secondary batteries are in their proper place in installations like the one described; it is a different matter altogether when a large installation is attempted.

To give some instances illustrating the economical side of the question, we will quote the Théâtre des Variétés in Paris, which is lighted by 250 Swan lamps, the necessary current for this installation being supplied by 270 Faure cells of 60 kilogrammes (over a cwt.) each. These are discharged in series of thirty; eight of these series are sufficient for the purposes of illumination, the ninth being held in reserve. A gas machine of 12 H.P. working 22 hours per day charges the cells by means of three Siemens machines D_2, a fourth being kept in reserve.

From exact calculations made by Mr. F. Geraldy, it appears that the expense of the electric light at the Variétés is six centimes (a little more than a halfpenny) per carcel-hour (light of 9·5 candles per hour) while with gas the expense would be three centimes per carcel-hour.

From another experiment, made at the Grand Hotel, Charing Cross, it appears that for the feeding of 80 Swan lamps during 6 hours, 80 Faure cells had to be charged during 14 hours by two Edison Z dynamos. Now, each of these machines would feed directly 60 Edison lamps of 9 candles each. Let us suppose the light of the Swan lamps to be likewise of 9 candles each; we find that by feeding the lamps from the machines direct, without the intermediary of secondary batteries, 120 lamps can be fed during 14 hours by the same mechanical work which supplies 80 lamps during 8 hours only; by the direct employment of machines we therefore obtain an illumination of one and a half times greater intensity and two and a third times longer duration. These figures speak for themselves.

The efficiency of the secondary batteries is given by Mr. Preece at 70 per cent.

One of the most successful installations carried out by the Electrical Power Storage Co. in this country is

Lloyd's Installation.

The lighting consists of 450 Edison Swan Incandescent lamps of 12 candle power placed in the Underwriters' Room, Reading Room, Committee Room, etc. A 20-horse-power Paxman engine, semi-portable type, drives 2 Elwell Parker vertical 4-pole dynamos to charge 174 of the Electrical Power Storage Company's Accumulators of the 31L type in glass boxes, which are capable of maintaining all the lamps for 9 hours after the engine has stopped. The lamps are arranged on two circuits, and as far as possible each room has half the lamps from each of the two supplies. The distributing apparatus consists of two main switchboards designed and made by the Electrical Power Storage Co., and placed in the dynamo room, from which all the lamps in the building are controlled, and special arrangements have been made to enable the number of cells to be varied not only in the discharging, but also in the charging circuit, and to insert an ammeter into either of these circuits as required, As a general rule the cells are charged at night, and the light is drawn entirely from the accumulators, which not only give a constant supply, but enable the light to be put on at any moment in the event of a sudden fog or darkness without the necessity of constantly keeping steam in the boilers. In the summer time it is only found necessary to charge once or twice a week in order to keep the cells fully charged and ready for use. Apart from the absolute reliability of the light when supplied from accumulators, there are many places in the City where it is practically impossible to run an engine during the day time, and there is no doubt that the accumulators will be found the easiest and most reliable solution of this difficulty.

Dynamos.

The different electric generators—magnetos and dynamos, continuous and alternating machines—adapt themselves almost equally well for electric lighting. In practice, however, certain machines are specially constructed to suit certain lamps.

We have already, on p. 137, stated the reasons for the almost exclusive use of continuous current machines for arc lamps; some differential lamps, however, like the Siemens, the Ganz, etc., employ alternating currents; in many cases arc lamps are worked with machines of a special type constructed by the inventor of the lamp. Instances of this kind are the Gramme, Siemens, Weston and Brush machines.

For all candles alternating currents are used; the necessity of an equal waste of the two carbons renders their use absolutely obligatory.

With the semi-incandescent lamps of Reynier, Werdermann, etc., continuous currents seem to give a higher efficiency.

Glow lamps adapt themselves for both kinds of machines equally well, although there has been a decided leaning towards continuous current machines.

If, as seems very probable, secondary generators come into common use, we may see a movement in the opposite direction, and a preponderance of alternating machines, especially for lighting with glow lamps from central stations.

Dr. Fleming* says that where ground is too expensive to admit of a central station, currents of high potential may be brought from a distance by light mains to a central room, and there be split up and distributed. The splitting up might be done by means of secondary generators, by secondary batteries, or by multiple conductors. Wilh. Siemens † also suggests that the main current of high potential should, by means of an auxiliary apparatus at the place of consumption, and which consumes very little energy be transformed into a current of lower potential. Secondary generators, as we have stated on p. 112 and following pages, seem exactly the sort of apparatus mentioned by Siemens; they consume very little energy, the waste being only about two per cent.

The number of arc lamps fed by one single machine is very variable. A single lamp fed by one machine constitutes a very expensive installation, and is only resorted to in special cases; as many as sixty divisional lamps have been placed in series in the same circuit. Electric candles are mounted in series by dividing the current supplied by the generator into several distinct circuits.

The most suitable arrangements for glow lamps have been fully discussed in several places; the only practical method is the parallel connection ensuring the independence of each individual lamp in one circuit.

The efficiency of the dynamo used for a special application naturally is of the greatest importance, and that the efficiency varies according to the machine employed is quite clear. One remark however must be made here: The dynamos in actual use at the present moment, when constructed by a well-known firm, such as Siemens, Schuckert, Crompton, Ganz, and several others, vary very little in efficiency, and the statements and quotations of these firms are entirely to be relied upon. This remark is not uncalled for; everybody who remembers the state of affairs in this country during the early days of electric lighting, must know that the wildest and most exaggerated reports were circulated for the mere purpose of speculation. The Paris Exhibition of 1881 has done a good deal towards enlightening, not only the general public, but also the professional electrician; and amongst the results obtained the tests of efficiency of different dynamos occupy a conspicuous place. They were made by Messrs. Allard, Joubert, Le Blanc, Potier and Tresca; and, as we have already referred to them on several occasions, we now give the results in the following tables, with some explanatory remarks.

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* *Electrician*, Feb. 14, 1885, p. 289.

† *Electrotechnische Zeitschrift*, p. 116, March 1883.

What is called *electrical horse-power* and *arc horse-power* represents an electrical work of 75 kilogrammetres per second (amount of work required to raise a weight of 75 kilogrammes through one metre) generally calculated from the current, resistance and electromotive force; *total mechanical efficiency* is the ratio between the total electrical work and the effective motive power; *mechanical efficiency of the arc* means the ratio between the work actually measured in the arc, and the same effective motive power; finally *electrical efficiency of the arc* means the ratio between the electrical work of the arc, and the total electrical work.

As regards the values given for the luminous efficiency corresponding to the expenditure of one electrical horse-power, and of one arc horse-power, it must be clearly understood that the photometric intensity designated by the term *mean spherical intensity** is used throughout these tables; it is in fact the only one which represents the luminous phenomenon in its entirety, and which therefore can be compared in a rational manner to the different factors producing this intensity. It must, however, be remarked that, by taking the requirements of public illumination as the basis of their estimates, the constructors of dynamos and lamps have naturally been led to much higher estimates of the efficiency of their apparatus.

These tests were made after uniform and reliable methods by a number of competent and impartial men; they were not made with the object of establishing the superiority of one or the other of the machines and lamps —such a comparison could only be the result of a very large number of determinations, sufficiently varied as regards each of the machines and lamps to establish with certainty the conditions which produce maximum effects—the only aim was to state in a more authoritative manner the results usually obtained in practice. From this point of view, the columns relating to the different efficiencies give most valuable information.

The chief aim of electric lighting is to make the largest possible amount of work available for the radiation of light, and the column of the tables giving the *mechanical efficiency of the arc* is therefore of paramount interest. On the other hand, *the illuminating power per mechanical horse-power* affords the first clue as to the cost of an installation, with due regard, of course, to the advantages arising from a rational division of light.

On referring to Table I. we find that a Siemens single arc light with 4·44 horse-power gives a mean spherical

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* See footnote on p. 277.

TABLE I.—TESTS OF CONTINUOUS-CURRENT MACHINES FEEDING ARC LAMPS.

Notations.	Formulæ.	I. Gramme, 1 lamp.	II. Jürgensen 1 lamp.	III. Maxim, 1 lamp.	IV. Siemens, 1 lamp.	V. Siemens, 2 lamps.	VI. Bürgin, 3 lamps.	VII. Gramme, 3 lamps.	VIII. Gramme, 5 lamps.	IX. Siemens, 5 lamps.	X. Weston, 10 lamps.	XI. Brush, 16 lamps	XII. Brush, 40 lamps.	XIII. Brush, 38 lamps.
Mechanical measurements—														
Speed of generator	Revs. per min.	475	800	1017	737	1330	1535	1695	1496	826	1003	770	700	705
Effective motive power	W horse-power	16·13	21·68	4·07	4·44	5·31	5·32	8·11	8·0	5·05	13·01	13·39	29·96	33·35
Electrical measurements—														
Resistance of machine, in ohms	”	0·33	0·45	0·7	0·66	1·68	2·8	0·52	4·57	7·05	1·88	10·55	22·38	22·38
Resistance of circuit without lamps	”	0·1	0·82	0·25	0·12	0·13	1·5	1·25	0·62	4·5	1·5	2·56	2·6	7·9
Total resistance	R, ohms	0·43	1·27	0·95	0·78	1·81	4·3	1·77	5·19	11·55	3·38	13·11	24·98	30·28
Current in ampères..	C, ampères	109·2	90·0	33·0	35·0	26·2	18·5	19·0	15·3	10·0	23·0	10·0	9·5	9·5
Difference of potential per lamp, in volts	E, volts	53·0	58·0	53·0	53·0	44·5	41·0	53·0	49·8	47·4	32·0	44·3	44·3	44·3
Results calculated from above—														
Work of entire circuit	$\frac{R C^2}{75\,g}$	6·97	13·99	1·41	1·29	1·69	2·0	0·87	1·65	1·57	2·43	1·79	3·07	3·72
Work of one lamp	$\frac{E C}{75\,g}$	7·87	6·97	2·31	2·52	1·59	1·027	1·369	1·04	0·64	1·0	0·6	0·573	0·573
Work of lamps in one circuit	w horse-power	7·87	7·09	2·37	2·52	3·18	3·08	4·11	5·2	3·2	10·0	9·6	21·88	20·79
Total electrical work	W^1	14·84	20·96	3·72	3·81	4·87	5·08	4·98	6·85	4·77	12·43	11·39	24·95	24·51
Mean electromotive force ..	$n\,E + R\,C$	102	172	84	80	136	203	193	328	353	398	840	2009	1971
Photometric measurements—														
Diameter of carbons	Millimetres	20	23	12	18	14	13	14	12	10	9·10	11	11	11
Luminous intensity, horizontal	Carcels	952	607	246	210	142	50	155	112	67	92	37	63	63
” ” maximum	”	1960	607	465	805	537	227	357	184	72	154	76	78	78
” ” mean spherical	l	966	688	239	306	205	82	167	102	52	85	38	39	39
Total intensity, mean spherical	$L = n\,l$	966	688	239	306	410	246	501	510	260	850	608	1560	1482
Efficiency—														
Efficiency, total mechanical ..	$\frac{W^1}{W}$	0·92	0·97	0·91	0·86	0·92	0·95	0·62	0·86	0·94	0·95	0·85	0·83	0·73
” of arcs	$\frac{w}{W}$	0·43	0·32	0·57	0·57	0·6	0·58	0·51	0·65	0·63	0·77	0·72	0·73	0·62
” electrical, of arcs ..	$\frac{w}{W^1}$	0·53	0·33	0·62	0·66	0·65	0·61	0·83	0·76	0·67	0·8	0·84	0·87	0·85
Carcels, per electrical horse-power	$\frac{L}{W}$	65·1	32·8	64·2	80·3	84·2	48·4	100·4	74·5	54·6	68·4	53·4	62·6	60·5
” ” mechanical ”	$\frac{L}{W^1}$	60·0	31·7	58·7	68·9	77·2	46·2	61·8	63·6	51·5	65·3	45·4	52·1	44·4
” ” arc ”	$\frac{L}{w}$	128·8	98·7	103·5	121·4	129·3	79·9	121·6	98·1	81·3	85·0	63·3	71·7	71·4
” ” ampère	$\frac{l}{C}$	8·85	7·64	7·24	8·74	7·82	4·43	8·79	6·67	5·2	3·7	3·8	4·11	4·11

TABLE II.

TESTS OF ALTERNATING CURRENT MACHINES FEEDING ARC LAMPS.

Notations.	Formulæ.	XIV. Méritens, 1 Serrin lamp. light house.	XV. Méritens, 6 Berjot lamps	XVI. Siemens. 2 lamps in 3 circuits
Mechanical measurements—				
Speed of exciting machine	Revs. per min.	0	0	1230·0
„ generator	„	870·0	874·0	620·0
Work expended by exciting machine, in horse-powers	„	0	0	2·6
Work expended by generator	„	11·7	12·28	13·79
Total motive power	W, horse-power	11·7	12·28	16·39
Electrical measurements—				
Resistance of exciting machine and of inductor	r, ohms	11·7	4·55	3·25
„ „ one disc or segment of generator	„	0·036	0·18	4·0
„ „ first circuit	„	0·036	0·41	0·62
Total resistance of one segment and of circuit	R	0·036	0·59	4·62
Resistance of the other circuits	R^1	0·036	0·72	8·0
Inducing current	c, ampères	0	0	16·0
Induced current of first circuit	C	0	32·6	12·8
„ „ other circuits	C^1	0	35·8	12·8
Fall of potential in the arc	„	0	36·0	55·2
Work of arc of the first circuit in horse-powers	„	0	1·56	3·77
„ „ each of the other circuits	„	0	1·71	3·77
Results calculated from above—				
Work of exciting machine	$\frac{r c^2}{75 g}$	0	0	1·13
„ the first circuit	$\frac{R C^2}{75 g}$	0	0·85	1·03
„ the other circuits	$\frac{R^1 C^2_1}{75 g}$	0	1·25	1·79
Total work of arc from direct measurements	w	0	8·4	11·31
Total electric work	W^1, horse-power	0	10·5	15·26
Photometric measurements—				
Diameter of carbons	Millimetres	23	20	10
Horizontal intensity	Carcels	1034	130,171	44
Mean spherical intensity	l	931	117,154	39
Total spherical intensity	L	931	733	468
Efficiency—				
Total mechanical efficiency	$\frac{W^1}{W}$	931·0	0·85	0·93
Mechanical efficiency of arcs	$\frac{w}{W}$	931·0	0·68	0·69
Electric „ „	$\frac{w}{W^1}$	931·0	0·8	0·74
Carcels per mechanical horse-power	$\frac{L}{W}$	79·6	59·7	33·3
„ electrical „	$\frac{L}{W^1}$	79·6	69·9	33·3
„ arc „	$\frac{L}{w}$	79·6	87·3	41·4
„ ampère	$\frac{l}{C}$	79·6	3·59	3·66

TABLE III.

TESTS OF MACHINES FEEDING ELECTRIC CANDLES.

Notations.	Formulæ.	XVII. Debrun with Debrun Mach. 7 candles.	XVIII. Jablochkoff with Gramme Mach. 20 candles.	XIX. Jablochkoff with Méritens Mach. 26 candles.	XX. Jamin with Jamin Mach 32 candles.	48 candles.	60 candles.
Mechanical measurements—							
Speed of generator .. per minute	Revolutions	2337	1206	861	2155	2300	2149
Work expended .. in horse-power	W	13·83	12·89	17·11	26·00	26·13	23·00
Electrical measurements—							
Resistance of exciting circuit, in ohms	r	..	·31	..	·50	·50	·50
„ first circuit „	R	..	4·8	3·90	12·7	12·7	12·7
„ other circuits „	R_1	..	11·2	14·90	34·5	34·5	34·5
Current of exciting circuit in ampères	c	..	53·3	0	25	25	25
„ light „ „	C	10	7·5	8·5	6·1	5·1	3·5
E. M. F. of candle .. .. in volts	E	50	43	42	77	69	74
Results from above—							
Work of the exciter .. in kilogram-metres	$\frac{r c^2}{g}$	..	90	0	32	32	32
„ in first circuit .. „	$\frac{R C^2}{g}$	..	27·54	28·74	48·2	33·7	15·9
„ in other circuits	$\frac{R^1 C^2}{g}$	..	64·26	114·22	139	91·5	43·1
Mean work in one arc	w	65·0	32·7	34·4	47·5	35·8	28·8
Total work in the arcs .. in H.P.	$w^1 = \frac{n w}{75}$	6·07	8·72	11·47	20·27	22·91	20·64
Total electrical work	W^1	..	11·15	13·0	23·09	25·01	21·85
Photometric measurements—							
Horizontal light intensity, in carcels	..	37·6	27·7	32·5	22·0	23·9	12·9
Mean spherical light intensity „	l	27·4	20·2	23·7	16·0	17·4	9·4
„ „ total light intensity in carcels	$L = n l$	192	404	592	512	835	568
Efficiency—							
Total mechanical efficiency	$W^1 : W$	..	·87	·76	·89	·96	·95
Mechanical efficiency of arcs	$w^1 : W$	·44	·68	·67	·78	·88	·89
Electrical „ „	$w^1 : W^1$	..	·78	·87	·88	·92	·94
Carcels per mechanical H.P.	$L : W$	13·9	31·3	34·8	19·7	32·0	24·5
„ electrical „	$L : W^1$	..	36·2	47·6	22·2	33·4	25·8
„ arc „	$L^1 : w^1$	31·6	46·3	51·6	25·3	36·4	27·3
„ of one candle .. per ampère	$l : C$	2·74	2·69	2·79	2·69	3·41	2·69

TABLE IV.

Tests of Machines feeding Glow lamps.

Notations.	Formulæ.	XXI. Maxim.			XXII. Edison.	XXIII. Lane-Fox.	XXIV. Swan.
		Weston-Cont.			Edison, large.	Edison, large.	
		100 lamps.	50 lamps.	25 lamps.	528 lamps.	6 lamps.	4 lamps.
Mechanical measurements—							
Speed of generator .. per minute	Revolutions.	984	1021	1027	282	..	..
Work expended .. .. .. in H.P.	W	23·0	17·12	9·15	68·74	..	..
Electrical measurements—							
Resistance of exciting circuit in ohms	r^1	1·75	1·75	1·75	..	..	..
,, light machine ,,	r	·05	·05	·05	..	..	..
,, one lamp ,,	R	47·2	42·8	41·0	130·0	28·0	31·1
Current of exciting circuit in ampères	C_1	32	32	32	..	..	..
Total current in light circuit ,,	C	142	87	50	370	..	..
Current per lamp ,,	$c = \frac{L^1}{n}$	1·42	1·74	2·00	·70	1·77	1·55
E. M. F. of one lamp .. in volts	$E = c\,r$	67	75	82	91	50	48
Results from above—							
Work of exciter .. .. .. in H.P.	$\frac{r^1 C_1^2}{75\,g}$	2·44	2·44	2·44	..	..	..
Work in light machine .. ,,	$\frac{r\,C^2}{75\,g}$	1·37	·52	·17	..	..	..
Work in one lamp in kilogram-metres	$w = \frac{R\,c^2}{g}$	9·71	13·22	16·73	6·50	8·95	7·62
Total work in lamps .. .. in H.P.	$w^1 = \frac{n\,R\,c^2}{75\,g}$	12·95	8·81	5·57	45·76	..	..
Total electrical work .. .. ,,	W^1	16·76	11·77	8·18	..	..	..
Photometric measurements—							
Mean spherical intensity, per lamp in carcels	l	1·44	2·80	3·77	1·57	1·64	2·19
,, ,, total intensity ,,	$L = n\,l$	144	140	94	827	..	..
Efficiency—							
Total mechanical efficiency	$W^1 : W$	·73	·69	·90	..	..	..
Mechanical efficiency of lamps ..	$w^1 : W$	·56	·51	·61	·67	..	..
Electrical efficiency of lamps ..	$w^1 : W^1$	·77	·75	·68	..	..	..
Carcels per mechanical H.P.	$L : W$	6·26	8·18	12·73	12·06	..	..
,, electrical ,, ...	$L : W^1$	8·59	11·89	11·49	..	..	..
,, H P. in lamps	$L : w^1$	11·12	15·89	16·88	18·12	13·74	21·55
,, of one lamp per ampère ..	$l : c$	1·01	1·61	1·89	2·24	·93	1·41

intensity of 306 carcels (column iv.), while Brush, with 29·96 horse-power and 40 lamps, obtains 1,560 carcels (column xii.). To produce the same illuminating power, five Siemens monophotal lamps would be required, consuming 22·62 horse-power. The expenditure of energy would thus be somewhat smaller, but the light would only be given out in five places, whilst with the Brush lamp 40 centres are obtained. We must therefore in many cases give preference to the Brush lamp, especially as the machinery required is also of a simpler character.

On comparing these data with the results obtained with the Edison glow lamp, we find from column xxii. (Table IV.) that 528 lamps with 68·74 horse-power give 829 carcels. This quantity of light can be produced by 2·7 Siemens single arc lights, and an expenditure of 11·9 horse-power; or, in other words, with 5·75 times less expenditure of energy. The light in the latter case would be very well divided, but the expense would be correspondingly large.

On taking, not the single arc light, but the Siemens differential lamp, we arrive at still less favourable results. On referring to column ix. (Table I.) we find that five lamps with 5·05 horse-power only yield 260 carcels; and, with an alternating current, twelve lamps only give 468 carcels, with 16·39 horse-power (column xvi. Table II.). The division of light is dependent not only on the construction of the lamp, but, in the first place, on the electromotive force produced by the dynamo. The difference of potential between the terminals of the individual lamps varies, according to the Paris tests, from 32 to 58 volts for arc lamps, from 42 to 77 for electric candles, and from 48 to 91 volts for glow lamps.

The larger the number of lamps *connected in series*, the higher must be the electromotive force between the terminals of the two extreme lamps. This E. M. F. is for

5 Siemens lamps (col. ix.) $47 \cdot 4 \times 5 = 237$ volts.
3 Gramme „ (col. vii.) $53 \times 3 = 159$ „
10 Weston „ (col. x.) $32 \times 10 = 320$ „

These figures show how many lamps of different electromotive force can be placed in circuit to replace the number of lamps given. If, for instance, Gramme lamps are to take the place of ten Weston lamps, we get $\frac{320}{53} = 6$ Gramme lamps, provided the relative resistance of the circuit is not materially altered by the change.

The resistance of ten Weston lamps is $= 14 \times 10 = 14$ ohms; that of six Gramme lamps is $= 2 \cdot 8 \times 6 = 16 \cdot 4$ ohms, not a very considerable difference, and one which need, as a rule, not be taken into account.

But it is quite another matter if we want to replace the Weston lamps by Siemens lamps. We get the number of the latter $\frac{320}{47 \cdot 4} = 7$ lamps; these 7 lamps have a resistance of $47 \cdot 4 \times 7 = 331 \cdot 8$ volts, and thus we find a difference of resistance of $331 \cdot 8 - 320 = 11 \cdot 8$ volts. Now a difference of $11 \cdot 8$ volts might in most cases be neglected, but not so the difference of resistance, which for seven Siemens lamps is $\cdot 7 \times 4 \cdot 74 = 33 \cdot 18$ ohms, while for the ten Weston lamps it is only 14 ohms. An approximate compensation might be effected by adding a second series of seven Siemens lamps in parallel connection, whereby the resistance would be reduced to $\frac{33 \cdot 18}{2} = 16 \cdot 89$ ohms; so that the ten Weston lamps would have to be replaced by fourteen Siemens lamps in two series of seven.

If we wanted to replace the ten Weston arc lamps by

Maxim glow lamps, which have a resistance of 41 ohms and E. M. F. of 82 volts (column xxi.), we find $\frac{320}{82} = 4$ lamps in series with a resistance of $41 \times 4 = 164$ ohms; to compensate for this resistance we require $\frac{164}{14} = 12$ parallel series of four lamps each; or forty-eight Maxim lamps would about replace ten Weston arc lamps.

We cannot do more than cast a rapid glance at the different practical applications of electric light, the object of this book being rather to afford to the electrician and the general public a clear insight into the construction, the efficiency and the mode of application of the various electric light apparatus than to describe the applications themselves. They are so numerous that they would fill a whole volume, and ought to be reserved for separate treatment; we find in all of them that the principles as to the mode of installation, connections, conductors, switches, choice of machines and lamps, etc., are essentially those which have been fully explained in the preceding pages, and that the only difference lies in details which recommend themselves from individual exigencies.

Amongst the most important applications are the following:—

1. *Illumination of Lighthouses.*

The first trial of electric light for lighthouse illumination was made in 1857 at Dungeness. On the recommendation of Faraday, Holmes was entrusted with the experiment. The electric light was finally installed at this lighthouse on the 6th June, 1862. The success of these experiments, and Faraday's favourable report, induced the Elder

Brethren of the Trinity House to order the Holmes machines for trial at the South Foreland, where electric light was installed on the 1st January, 1872, and has been successfully worked ever since.

On the 26th December, 1863, the lighthouses of La Hève, in France, were for the first time lighted by electricity with the Alliance machine, and since that time all the more important French lighthouses have followed suit; and also in England and the Colonies, the electric light has to some extent ousted not only the oil lamp, but also the Drummond light.

A special Commission appointed by the Trinity House has made extensive trials at the South Foreland, and has arrived at the following conclusions:—

1. That electric light is the most powerful under all conditions of weather; that it possesses the greatest penetrative power in fog.

2. That for the ordinary necessities of lighthouse illumination, mineral oil is the most suitable and economical illuminant; and that for salient headlands, important landfalls, and places where a very powerful light is required, electricity offers the greatest advantages.

There are several other points mentioned as to the relative cost and efficiency of gas and oil which need not be mentioned here. The lamp employed at the South Foreland was the Berjot lamp with Siemens carbons. The three magneto-electric machines which supplied the current were of the De Méritens type, and were driven at a speed of 600 revolutions per minute. The illuminating power of the two naked lights was 10,000 and 15,000 candles respectively.

2. *Ship Lighting.*

On board a steamship, electricity can be economically produced, because it is always easy to take a few horse-power from the engines to drive the electric generator; the question of expense, therefore, does not stand in the way of the application of electric lighting to steamers.

We find in fact that all the large steamship companies are introducing electric light for the illumination of their saloons and cabins.

The Swan lamp has been extensively introduced by some of the largest companies. The Inman Company's steamer *City of Richmond* was the first ship lighted with Swan lamps. They have been regularly in use since June, 1881, and have given the greatest satisfaction.

There are sixty lamps installed; forty-eight are hung in plated pendants with obscured globes. Each pendant is fitted with two lamps. The lamps at the companion staircase and in the passages are hung from plated brackets of ornamental design. The lamps are attached to the pendants and brackets by the spring holders (v. p. 282), which are specially adapted for use on board ship; for, whilst they keep the lamp in perfect contact, they allow a certain amount of movement which prevents the lamp being affected by the vibration of the ship. The wires conveying the current are attached to each side by the binding screws, which are in contact with the hooks holding the lamp.

The electricity is generated by a Siemens alternating machine, driven by an ordinary steam engine placed in a small room adjoining the main engine-room, and supplied with steam either from the main or donkey-boilers. From this machine two insulated main leading cables are laid to the saloons, etc., with insulated branch wires to each of the lamps. At each point where these branches are attached a switch is fixed for turning out the lamps when desired; it is so arranged that it cannot be turned except with a peculiar kind of key, which is in possession of the steward; and the form of the key makes it necessary for the switch either to be fully off or fully on before the key can be removed, thus preventing sparking. These switches are also each fitted with a safety fusing connection, to prevent risk of fire.

But not only for mercantile shipping, but also for the navy, the question of electric light has become of the greatest importance. The new engines of naval warfare have brought about a complete change in naval tactics; the powerful ironclads have called into existence an enemy, the torpedo. The torpedo is fired by electricity; but, in order to produce the desired effect, it must first of all be brought close to the enemy's vessel. This is done by means of a torpedo-boat, a small steam-launch of the highest possible speed, which has to place the torpedo under the hulk of the vessel without being seen, and to make off immediately afterwards. It is, therefore, indispensable for large ironclads to have an electric lamp on board, which allows them to explore the horizon and to discover the approach of a torpedo-boat at night.

Another use of the electric lamp on board a man-of-war is to light up the coast where a landing is to be effected, and also forts which are to be bombarded. The landing of the French on the coast of Tunis, of the English in the late Egyptian war, the bombardment of Sfax, Gabès, etc. by the French, and of Alexandria by our navy, are well-known instances, still fresh in our memories, of the immense importance of electric light in naval warfare.

Experiments made on board the French ironclad *Richelieu* with two different types of lamps, the one regulated by the hand, the other automatic, have resulted in the adoption of the hand-regulated lamps by the French navy. In these lamps the distance of the carbon points is regulated by means of a screw and a little fly-wheel, in proportion to the waste of the carbons. The lamps are provided with metallic contacts which establish electrical communication with the conductors leading to the projector (a large reflecting mirror), and with two terminals for operations independent of the projector. The lower carbon is insulated from the frame and receives the conductor of the negative pole. The upper carbon is in connection with the frame and receives the conductor of the positive pole.

The following are stated to be the advantages of the hand-regulated lamp over the automatic one:—

Facility and rapidity of priming and lighting.

Possibility of instantly obtaining the required length of arc.

The carbons can be withdrawn as much as the speed and power of the motor will allow, and can thus furnish the highest possible luminous intensity.

Independence of the apparatus of the movements of the projector and the vessel.

Possibility of pressing the carbons against one another, so as to remove their excrescences.

The mechanism is simple and solid, and comparatively inexpensive (£12 instead of £32 for an automatic lamp); the repairs can be easily executed on board.

The carbon-holders need not be vertical; they can be held in an inclined position, and this reduces to a considerable extent the necessary displacement of the upper carbon.

The ironclad ought, therefore, to be provided with one hand-regulated lamp for each projector, one reserve lamp of the same kind, and, if occasion requires, one automatic lamp for special cases where the light has to be maintained in a perilous position which would endanger the life of the person in charge. The electric current on board the *Richelieu* is generated by a Gramme machine (type D) driven by a Brotherhood three-cylinder engine, to which it is coupled direct. This direct coupling recommends itself for all electric light installations wherever practicable. Not only does it do away with this most dreadful nuisance, the sliding of the driving belt, but it allows the working of the dynamo at a higher speed, and thus ensures greater efficiency.

Messrs. Crompton and Co.* have constructed a self-regulating differential focussing lamp for similar purposes. It is of the same type as the D D lamp, and is provided with a compensating lever, by which arrangement the amount of carbons consumed does not alter nor disturb the equilibrium of the lamps, and a very small movement of the solenoid, or armature core, gives a comparatively great travel to the carbons, and thus makes the lamp very sensitive. To bring the focus of the lamp in the focus of the parabolic mirror, it is adjusted by a milled-headed screw in the vertical and by a similar screw in the horizontal direction. The whole of the working parts are below the carbons and enclosed in a light wrought-iron casing, with a sliding door on both sides, to give access to the parts of the lamp. The case is fitted to a rolled steel tube, fitted with a strong gun-metal casing on both ends. In one end is mounted a 24-inch diameter Chance parabolic mirror (this is a decided advantage in cost to the usual dioptric lenses). The mirror is fastened and held in position with springs at the back, to prevent injuries by concussion due to the firing of heavy guns At the other end is a strongly hinged gun-metal door, carrying a thick plate-glass front, provided with a neat and simple fastening for opening and closing. The steel cylinder is fitted with gun-metal trunnions which rest in gun-metal bearings held in a strong wrought-iron fork, which is fixed into a movable cast-iron top and passes through into the lower cast-iron base for turning in the horizontal plane. On one side of the trunnion is fixed a quadrant and worm for raising and lowering in the vertical through a certain angle. In the cast-iron base are fixed the contact rings and sliding brushes to supply the current to the lamp in any position. On the outside of the base is also fitted a switch, on either side of which the cable enters and is connected up. Two of these search lights with projectors of 25,000 candles each have been constructed for the Brazilian ironclad *Aquidaban.*

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* *Electrician*, No. 14, 1885, p. 286.

The projector in general use, both in France and in this country, is *Mangin's.* The hand-worked lamp described above is placed inside the apparatus; the reflecting spherical surface of the glass mirror is on the inside, and the ray must therefore twice traverse the thickness of the mirror before receiving its final direction. The two surfaces are not parallel either, the interior surface being a sphere, which has not the same radius as the other. The different thicknesses which the respective rays have to traverse, according to the angle they form with the axis, modify their direction so as to bring them back to strict parallelism, provided the radii of the two spherical surfaces are of proper proportion. As regards the inclined positions of the carbons, it has been found that, on employing a continuous current, the ray of maximum luminous intensity does not lie in the plane perpendicular to the line of the carbons, but about 30 degrees below it.

But not only for men-of-war, but also for our transatlantic steamers, the use of an electric light and projector might be of the greatest value. It is well known that towards the autumn equinox, immense masses of ice are detached from the northern coast of Greenland and carried south by a powerful current. The track of the outgoing steamers takes them very near to Cape Farewell, the southern extremity of Greenland, and their meeting with floating icebergs is by no means a rare occurrence. The approach of these formidable enemies at night constitutes a great danger for the vessel, and this danger could easily be averted by the employment of an electric search light.

3. *Night Signalling.*

The electric light has also been applied to night signalling on board the French ironclad *Colbert,* Swan lamps having taken the place of oil or petroleum lamps, which are hoisted in two groups of five along the mainmast—the first group to the masthead, the second below the mizen-yard; the different signals constituting the International code are obtained by varying the number of lighted lamps or their respective positions. Each lamp is placed in a shunt of one branch wire, and all the shunts lead to a commutator, from whence, by pressing a stud, each lamp can be turned off or on as the case requires. Another branch conveys the current to a lantern suspended from the gaff, which is intended to light up all the points of the horizon. The lantern contains a Berjot lamp, indicates the position of the vessel, and secures it against collisions.

Finally, a third branch conveys the current to a Colomb lantern placed on the captain's bridge, and intended for a sort of official telegraphy. The lantern is only visible from one quarter of the horizon, and is provided with a screen, which by means of a rod and a cord can be raised or lowered, so as to completely and alternately hide the light, and so to produce a veritable optical Morse alphabet. The lantern can be fitted either with a large glow lamp or with a Jablochkoff candle.

4. *Electric Light in Collieries.*

The first practical application in the United Kingdom of the electric light to the illumination of coal mines was made on the 9th August, 1881. The Garnock Colliery, near Hamilton, Lanarkshire, belonging to Mr. Watson, was fitted up with Swan lamps specially arranged with outer lanterns of stout glass, air tight, and provided with steel guards. The workings in which the lamps were fixed were 118 fathoms or 708 feet below the surface. Twenty-one brilliant little lamps placed at the pit-bottom in the roads, and at the actual face of the seam where active operations were in progress, supplied an illumination of a very different character from the dismal glimmer of an occasional Davy lamp. The electricity was generated by a dynamo at the surface, worked by a special twelve horse-power engine and conveyed by two cables, first along telegraph poles to the pit-mouth, then down the shaft to the workings in one section to a distance of half a mile. The overhead wires were naked copper wires of three-eighths of an inch diameter, while those below ground were carefully insulated, and in the shaft were protected with an outer tube of galvanized iron. At suitable points of the circuit air-tight safety switches were inserted, to afford control over individual lamps.

The risk of accident must be considered immensely less than that of the ordinary Davy lamp, especially when it is remembered that, with the brilliant light of the electric lamps, they need no longer be carried in the hand or set down upon the floor near the actual spot where the coal is being got, but can be fixed overhead at a safe distance against the wall of the mine. The ease with which the lights can be turned out during the firing of a blast is another point in their favour.

A safety glow lamp has been constructed by Mr. Swan which seems to fulfil all the necessary requirements of such an apparatus. The lamps are enclosed in lanterns and are calculated to give the light of two or three candles; they are so attached to the conducting wires that good contact is made with them, and the renewal of the lamps can be effected with great ease. The lantern has a ring at each end for suspension in either an upward or a downward position; and there is a second central contact to connect the lantern with the cable containing the conducting wires in communication with the electric generator.

In connection with the lamp there is a portable secondary battery contained in a small wooden box, which renders the safety-lamp independent of the main wires conveying the current from a distant dynamo.

The dynamo, however, would still be required, even with the portable cells; for what is contemplated is that the portable secondary cells contained in the box should be taken to the dynamo to be charged, and after being so charged, these portable stores of energy should be sent into the pit-workings on trucks, there to be connected with the lamps.

A set of cells, weighing about twenty pounds, would keep a lamp lighted for about eight hours, and the actual cost of supplying the current and keeping the lamp lighted would be very small—probably less than the cost of oil for producing an equal amount of light by the ordinary pit lamps. The weight of the lamp is a pound and a half, and the weight of the box nine pounds and a half.

These lanterns may be transported without fear of accident. The lamp bulbs are of very fragile glass; at the same time, any explosion consequent upon the breaking of a lamp is prevented, since the air inside the lantern would be sufficient for the instantaneous combustion of the carbon filament before the flame could be communicated to the outside air.

A number of collieries have introduced electric light; but the progress in this direction is very slow, which is the more to be regretted as it cannot be doubted that the universal adoption of electric light in fiery mines would reduce the death-roll of persons killed by explosions of fire-damp in Great Britain to one-tenth of its terrible proportions, which in 1880 reached 499 persons. It is to be hoped that before long the Royal Commission for reporting on accidents in the coal-mines of the United Kingdom, which has been deliberating for years, will recommend the passing of an Act of Parliament to make electric lighting compulsory in coal mines.

The colliery owners themselves will discover, when driven to this course by compulsion, that in the long run they effect an economy by discarding the clumsy and unsafe "safety" lamp, which will soon be consigned to the lumber room.

5. *Application to Military Operations.*

A number of applications for naval operations have been given in two of the preceding articles. The light can further be used for reconnoitring fortifications, for watching the erection of defensive works and the firing of batteries, for preventing a surprise on the opening of a trench, for lighting up a breach, etc.

For the purposes of reconnoitring, for instance, a Gramme machine with the driving Brotherhood motor and Mangin projector, is placed on a strong carriage, and by a detachment of cavalry taken to the designated spot. Steam is got up before starting, and on arrival the projector is conveyed to a short distance, if possible to elevated ground, and placed on a four-wheeled support or strong pivoting saddle which is also fixed to the carriage. The conducting wires are at the same time fixed to connect the projector to the machine, and the light is either directed to all parts of the horizon, or fixed on a definite object, as, for instance the fortifications of a town to be bombarded. These apparatus have a considerable power of projection, and render the buildings of a town visible at a distance of 9,500 metres (about 6 miles). This apparatus can, however, on account of its weight, only be used on comparatively level ground; for mountainous regions, Messrs. Sautter and Lemonnier of Paris, have constructed a carriage with a small Gramme machine and projector which can easily be drawn by one horse, and can, moreover, be entirely taken to pieces; the whole can be carried on a mule's back, and the light can therefore be produced at any spot to which mountain artillery can be taken.

6. *Illumination of Railway Trains.*

It would appear that on account of the unavoidable vibration and the frequent shocks to which a railway train is exposed, glow lamps only could be used for illumination, and in fact, the ordinary arc lamps are wholly unfit for this purpose. An arc lamp has, however, been constructed by Sedlaczek and Wikullil which has been successfully used for locomotive head-lights. This system was tested at Paris during the Electrical Exhibition, and more recently on the Chemin de fer du Nord, between Paris and Dammartin, and also on the Kronprinz Rudolf Bahn, in Austria

The lamp consists of two vertical tubes of different diameters and connected at the bottom; two pistons carrying the carbons move in these tubes, which are filled with glycerine. In the lower part of one tube is a small hollow piston connected to a lever, and maintained in position by a spring; at its other extremity the lever terminates in an armature, which is opposed to an electro-magnet of feeble resistance, through which the current feeding the lamp passes constantly. The two tubes communicate by means of a small opening in the hollow piston, and the pistons moving in the two tubes consequently take up a position of equilibrium, which is regulated in such a way that, when at rest, the two carbons are in contact as soon as the current passes, the arc offering no resistance, the electro-magnet is strongly energized and attracts the lever. The small hollow piston moves to the right and closes the communication between the two tubes; at the same time it causes a slight lowering of the level of the liquid in one tube, and consequently a withdrawal of the lower carbon.

The electric arc is now formed, and from this moment the hollow piston acts as a regulator, establishing or closing the communication between the two tubes, that is to say, bringing about an approach or a withdrawal of the carbons in proportion as the arc increases or diminishes. As used for a locomotive head-light, the lamp is mounted in a wooden case attached to the front of the smoke-box, so that the bottom of the case is on a level with the highest point of the boiler. In front of the bottom of the boiler are placed a Schuckert dynamo (for experiments made in Austria), or a Gramme dynamo (for experiments made in France), and a three-cylinder Brotherhood engine. Such a lamp was found sufficiently powerful to illuminate a space of about one-third of a mile, and its efficiency was particularly evident in tunnels and for distinguishing signals. By a very simple arrangement the lamp can be rotated round its axis by the engine-driver, so as to throw a light in various directions.

This is one of the tasks electric light is called upon to fulfil with regard to railway travelling; the second task is the illumination of the carriages, and for this purpose we cannot do better than give an account of the installation adopted for the Pullman Limited Express between London and Brighton.

The train contains four Pullman cars, and can accommodate 113 passengers. The front luggage van contains two batteries of 32 Faure accumulators. Each of these batteries can be placed in communication with two cables extending from one end of the train to the other, and on which the Edison lamps are mounted in shunts. These two groups of accumulators are enclosed in boxes of 1·8 metre in length, 60 centimetres in width, and 1·4 metre in height, the whole weighing about 600 kilogrammes. These batteries are charged at Victoria before the departure of the train. The electricity is produced by two Gramme machines driven by a gas engine of 6 horse-power. The charging of the batteries requires about 10 hours. When it is finished the machine charges other accumulators placed in the same room, and which serve for lighting one of the platforms of the station with Maxim lamps.

In the train, during the day-time, the lamps are lighted when passing through a tunnel, at night the lamps remain constantly lighted. The light is steady and not fatiguing to the eyes.

The Edison lamps are fixed to the ceiling by means of the old oil-lamp supports, and were originally provided with the old lamp-shades. The batteries can maintain the incandescence for five hours; this is apparently the minimum obtained with the apparatus employed. In this particular case, the solution of the problem of electric lighting is comparatively easy, for the carriages are coupled for a considerable time, and need, so to say, never be uncoupled. The cables are continuous from one end of the train to the other, without any special coupling between the carriages; but this would be otherwise if the carriages had to be frequently separated. Even in this case, however, the necessity of keeping the train for ten hours near the charging machine presents a serious inconvenience. To remedy this defect, a Siemens machine is placed in one of the luggage vans of the train, and is driven by connecting it to one of the wheels of the van. A small hand-worked switch permits the change of the direction of the current simultaneously with any change in the direction of the train. Under these conditions, the current of the Siemens machine will pass constantly through the battery cells, as well as through the lamps.

When the speed of the train is slackened to such a degree that the current of the dynamo is feebler than that of the secondary battery, an automatic cutout interrupts the communication between the machine and the accumulators, and the latter only feed the lamps.

7. *Illumination of Theatres.*

The first use of electric light for purposes of stage lighting dates back as far as 1846, and was made at the Paris Opera, where the skating scene in Meyerbeer's "Prophet" was illuminated by electric light, much to the astonishment and the delight of the public.

Since then electric light has found its way into many theatres all over the world, not only for stage lighting, but for lighting up the whole house.

We confine ourselves here to the description of the installation at the Savoy Theatre, which presents some features of interest.

This theatre is lighted by 1,158 Swan lamps; of these 114 are placed in the auditorium, arranged in groups of three, and supported by elegant brackets along the different galleries. Each lamp is enclosed in a globe of ground glass, and gives a very soft and pleasant light.

Two hundred and twenty lamps are employed for lighting the numerous corridors, passages and boxes of the theatre, while 824 are placed on the stage. These latter are distributed in the following manner:—

6	rows of	100	lamps each,	above the stage . . .	600
1	row of	60	,,	,, . . .	60
4	rows of	40	,,	on the uprights . . .	160
2	,,	18	,,	,, . . .	36
5	,,	10	,,	for footlights	50
2	,,	11	,,	,, ...	22
					824

Besides the lamps mentioned, eight test-lamps are placed in the machine-room; they serve for lighting the room, and as they are in the same circuit as some of the lamps of the auditorium, they indicate, by the change of their lighting power, when the lamps on the stage are extinguished or lighted.

The lamps are mounted in shunts in six groups, five of which consist of 200 lamps each; the sixth of 170 lamps. The current of each group is produced by an alternating Siemens dynamo, type W, which is excited by a Siemens D. The machines and driving engines are placed in a shed erected in an open space near the Victoria Embankment, and the current is conveyed to the theatre by means of insulated underground cables. The six alternating machines make 70 revolutions, and the six exciting machines 1,150 revolutions per minute. They are driven by three steam engines—a Garrett movable engine of 20 horse-power, a Marshall movable engine of 12 horse-power, and a semi-portable Robey engine of 20 horse-power; but the horse-power actually expended, measured by Hefner Alteneck's dynamometer, is 120 to 130. It must, however, be mentioned that, in addition to the twelve machines for feeding the 1,166 glow lamps, there is also a Siemens D_2, which feeds the powerful arc lamp suspended outside the theatre above the main entrance, and that the force for driving this machine is included in the above figures.

The most interesting feature of this installation is the method by which the lamps in all parts of the establishment are worked; for any one of the series of lamps can be turned on at any moment to full power, or gradually lowered to a feeble red glimmer, as easily as if they were gas burners, by simply turning a handle. There are six of these regulating handles—corresponding to the number of machines and circuits—placed side by side against the wall of a closet on the left of the stage. Each of these handles acts on a six-way commutator, by means of which a greater or lesser resistance can be introduced into the corresponding circuit (gradually increasing or diminishing it by six successive charges); the strength of the current traversing the lamps is hereby diminished or increased by as many degrees. The special interest attached to this part of the installation consists in the fact, that the lowering of the lamps is accompanied by a corresponding economy in the motive force of the machine, as the variable resistance which is introduced by the regulating handles is not introduced in the external circuit either of the lamp or of the alternating machine, but in the exciting circuit; therefore, when a series of lamps is lowered, an increased resistance is produced in the circuit of the machine which excites the field magnets of the alternating dynamo corresponding to this particular series of lamps, the intensity of the magnetic field of the latter machine is thus reduced, and consequently the currents of this machine are diminished; but through the weakening of the magnetic field, the mechanical resistance is reduced in proportion, and the machine expends less energy. The resistances introduced into the circuits are of two kinds: the four commutators to which we have alluded cause the current to pass through long spirals of iron wire, supported by a frame, and having a free circulation of air around them in order to reduce the heat generated by the current; and the commutators of the two other circuits act in a similar manner on resistances composed of zigzag-shaped iron bands arranged in the same way.

8. *Electric Light applied to Photography.*

To obtain good photographic results with electric light, the lighted field must be large and very uniformly illumined. The light produced need not be fixed for a long period, since it has often to be extinguished every six or seven minutes; but during this time a surface of several square metres must be illumined in the most brilliant manner possible.

Dujardin has obtained this result by employing two arc lamps, with progressive and continuous movements placed in the same circuit; the lamps are fed by two Siemens dynamos (medium size) coupled for tension and performing 850 revolutions per minute. With carbons of 14 mm. diameter arranged in such a way that the lower carbon is slightly in advance of the axis of the upper one, whereby the crater of the upper (positive) carbon presents itself under an angle of 45°, without any other reflector than the crater, a projection of light has been obtained equal in intensity to pale sunlight. The value of this illumination has been estimated by Dujardin at 1,800 carcels, or 900 carcels (8,500 candles) for each lamp.

Dujardin uses the Serrin lamp, removing its electromagnetic check. The lighting is effected in the usual way, but the clocktrain, when once released, causes a continuous advance of the carbons, which has been calculated according to their duration, and which prevents all the slight irregularities existing in all electric lamps, however perfect they may be. Under these conditions, the flame of the arc envelops the upper carbon in a perfectly regular manner, and assumes a tulip-like shape, which is the most convenient for a steady brilliant light. With the ordinary lamp this flame is flickering and irregular. Dujardin is also of opinion that, by placing the two lamps in the same circuit, he contributes to the regularity in consequence of the compensations which result from their reciprocal action. He has also found that the resistance of the arc is much larger than is generally believed, on account of the counter electromotive force arising from polarization, which is developed on the carbons; and this is confirmed by Edlund and by Jamin. He therefore placed his two dynamos in tension on the same circuit, and found that in this way their action was more regular. Dujardin uses the horizontal Siemens dynamo, and drives it by an engine of 9 horse-power.

The fitting up of the light apparatus is most simple. At the end of a long passage painted in dark colour is a reflecting sheet to which are fastened the engravings, photographs, or drawings to be reproduced; and facing this surface, about two metres apart, are installed on the sides of the passage two lamps, which are, on the side opposed to the sheet, covered by a sort of circular screen painted white. This screen serves at the same time for hiding the luminous points from the photographic apparatus, and for throwing the light on the reflecting sheet. Behind the lamps, and in the middle of the passage, are the dark chamber and its accessories for photographic reproductions. Dujardin is so well satisfied with the results obtained by this installation, that he never makes use of daylight for his photographs.

9. *Electric Light applied to the Microscope.*

The lamps constructed for this purpose are Swan lamps, and were adapted for the application named by

Mr. Stearn, Mr. Swan's colleague. The length of the incandescent filament is $\frac{1}{10}$ of an inch, its diameter $\frac{1}{100}$ of an inch. Two Bunsen cells, or four Leclanché's are sufficient to render them fully incandescent; but for general purposes it will be better to use an additional cell, regulating the intensity of light by means of an adjustable resistance, attached to the base of the microscope. It is possible to obtain a light of 2½ candles from the tiny surface just mentioned, with an electromotive force of 3½ volts, and current of 1¼ ampère. It would, however, at a safe temperature, give a light of one candle.

For the illumination of opaque objects, the lamp is attached by a pointed arm to an insulated collar which screws on above the objective. The source of light can thus be rotated around the objects while under examination, so that delicate surface markings can be readily brought out.

By simply turning a switch, the current can be made to pass to another lamp, mounted on a platform fitting into the sub-stage, and capable of rotation and lateral adjustment, so that direct or oblique illumination at any angle may be obtained.

As the source of light is almost a point, and the lamp can be brought very nearly in contact with the slide, a higher degree of obliquity of the illuminating rays can be obtained than by almost any other method; and hence black-ground illumination is shown with greater beauty, and many of the diatoms display diffraction colours with unusual splendour.

For use with the polariscope, a third lamp of slightly larger size is placed in the position of the usual mirror. This requires an additional cell, so as to develop a light of about 4 candles.

As the sockets of the lamps are all made to a standard size, it is easy, if a larger light than is given by the smaller lamp be required, to transpose the larger one to either of the above positions, and use the full strength of the battery. It is found desirable with the lower powers to give parallelism to convergence to the rays; a very small lens can be mounted in front of the lamp, and the lamp can thus be placed in any position above or below the stage.

If it is required to maintain the lamps for several hours at full incandescence, then the most satisfactory battery to use would be Bunsen or Grove. If, however, the switch is turned off whenever an observation is completed, a modification of the Leclanché answers admirably. It is best to use five of the Leclanché cells, controlling the strength of current by means of the resistance, and thus diminishing it as the potential of the battery falls.

10. *Application of Electric Light to Surgical Operations.*

The property of the electric current of raising inferior metallic conductors, such as platinum, iridium, etc, to incandescence was utilized in surgery by John Marshall in 1851, by Leroy d'Etiolles in 1853, Mideldorf in 1854, Broca in 1856, etc.

The lighting was attempted at a more recent date, in 1867; Dr. Bruck, a dentist at Breslau, brought out an apparatus for lighting up the buccal cavities, to which he gave the name of stomatoscope. A little later, Dr. Millot, in France, made numerous experiments for lighting up the stomachs of animals at the École Pratique in Paris.

The attempts were not successful, on account of the inconstancy of the electric source (Grove and Bunsen cells), which necessitates the use of very thick platinum wires, in order not to expose them to volatilization. Luminous effects were obtained, it is true, but at the same time calorific effects of such intensity as to render this method of lighting impossible. A circulation of water was established to counteract the heat produced, but the apparatus were too cumbersome and difficult to handle, and have not been adopted in practice.

Gaston Planté indicated, as early as 1868, the application of this secondary battery for this purpose, and carried it into effect in 1872.

In 1873 Dr. Onimus performed, with Planté's apparatus, cauterization of the lachrymal gland on seven or eight individuals, without recharging the apparatus. Trouvé has added to Planté's apparatus a rheostat with platinum wire for the regulation of the current-strength, according to the length and the diameter of the platinum wire used for lighting or for cauterizing. He also added a galvanometer with two circuits to control the charge of the secondary cell and the condition of the charging battery.

This apparatus is called a *polyscope*.

By the help of the rheostat, platinum wires of from $\frac{1}{15}$ to $1\frac{1}{2}$ millimetre in diameter can be heated for several hours to the point of fusion without ever exceeding that point. Trouvé uses instead of platinum spirals, thin wire flattened in the middle, so as to form a small incandescent disc. The luminous power is thereby sensibly increased, as has been proved by Captain Manceron, in his experiments of lighting up the interior of guns at St. Thomas d'Aquin. For lighting of cavities Trouvé uses a series of spherical reflectors, concave or parabolic, with or without mirrors. A handle and conducting wire connect these reflectors with the battery case.

Payne's Apparatus for Illumination of Internal Cavities by Electric Light.

Remembering that Sir Henry Thomson explored the bladder by means of electric light, and that Leitz, of Vienna, devised instruments for illuminating the throat, bladder, uterus, etc., Mr. Payne first made an instrument by means of which the throat could be examined. He subsequently succeeded in constructing an apparatus which enabled him, on performing the operation of abdominal section with incision of the liver, to light up the interior of the cyst by means of the electric light. The instrument consists of a brass tube electroplated, 9½ inches in length, and $\frac{11}{16}$ of an inch externally. One end of this tube is funnel-shaped, and the other is closed by a piece of glass. A Swan lamp is used, which is hermetically sealed in a glass shade, and water, conveyed to and fro through very small brass tubes, is made to circulate round the lamp. For prolonged observation either a Grove or Bunsen battery is preferred, but for ordinary purposes four cells of a modified Leclanché battery are employed. It is advisable to have as great a pressure as possible for the water supply, so as to ensure perfect circulation; and for this a tin can containing water is suspended from a hook fixed near the ceiling of the room, connecting it with the brass tubes by means of lengths of indiarubber tubing.

Dr. Boisseau du Roché's Megaloscope.

A similar instrument has quite recently been constructed by Dr. Boisseau du Roche, of Paris. It is a probe, 600 mm. long and 6 mm. wide, at the bottom of which is a small

Swan lamp, and whilst an optical apparatus consisting of a prism and two opposite convex lenses is placed above the lamp, an image on a reduced scale of the cavity to be examined is thus produced, and is observed in its normal dimensions through a telescope forming the top part of the probe.

Two cells of a bichromate battery specially constructed by the inventor feed the lamp.

Further applications of electric light, as for instance, for the acceleration of building operations, for the gathering of harvests, for submarine constructions and explorations do not require detailed description. Enough has been said in the preceding pages to show the wonderful adaptability of the new illuminating agent to purposes of the most varied description. We may safely predict for it a most successful future, and although it has not made the rapid strides it was expected to make at the outset, yet—"*Chi va piano, va sano e va lontano.*"

INDEX.

A.

Ammeter, Ayrton and Perry, 55
——, Lalande, 58
Applications of electric light, 330
—— dynamos, 337
—— secondary batteries, 330
—— lighthouses, 347
—— ships, 349
—— night signalling, 354
—— collieries, 355
—— military operations, 358
—— railway trains, 359
—— theatres, 362
—— photography, 365
—— microscope, 366
—— surgical operations, 368
Arc, intensity of, 153
Arc lamps, 140
—— monophotal, 164
—— —— Archereau, 166
—— —— Bürgin, 173
—— —— Crompton, 177
—— —— Foucault-Duboscq, 165
—— —— Jaspar, 167
—— —— Jürgensen, 170
—— —— Siemens, 171
—— —— Solignac, 182
—— oblique carbons, with, 245
—— —— Heinrich, 247
—— —— Rapieff, 246
—— Polyphotal, 185
—— —— Brush, 197
Arc Polyphotal Bürgin, 187
—— —— Crompton, 180
—— —— Fontaine, 187
—— —— Gérard, 207
—— —— Gramme, 189
—— —— Gülcher, 225
—— —— Lever, 205
—— —— Mersanne, 209
—— —— Pilsen, 220
—— —— Serrin Lontin, 185
—— —— Siemens, 216
—— —— Street and Macquaire, 228
—— —— Tchikoleff, 224
—— —— Thomson-Houston, 210
—— —— Weston, 192
—— —— Zipernowsky, 212
—— —— at Paris, 158, 341
—— —— Vienna, 157
—— —— Philadelphia, 162
—— —— general remarks on construction of, 232
—— —— and glow lamps parallel, 126

C.

Carbons for arc lamps, 143
Candles, electric, 250
—— Jablochkoff, 250
—— Jamin, 254
—— Sun lamp, 257
Central Stations for Arc lighting, 95
Central Station, Berlin, 105
Current meter, Edison, 69
—— regulator, Brush, 98
—— —— Thomson-Houston, 100

D.

Difference between arc- and glow-light, 6
Distribution of heat in circuit, 15
Dynamos, efficiency of, 28
—— at Paris, 48, 158, 341
—— at Health Exhibition, 50
Dynamometer, Siemens, 53

E.

Ergmeter, Ayrton and Perry, 73
Electricity meter, Aron, 74
Electric light, cost of, 128
—— —— precautions against risks, 136

G.

Galvanometer, universal, Siemens, 62
Generation of heat and light by current, 7
Generator secondary, 115
—— —— Gaulard and Gibbs, 115
—— —— Zipernowsky, Déri and Blathy, 117
Glow lamps, 259
—— —— semi-incandescent, 263
—— —— —— Reynier, 263
—— —— —— Werdermann, 266
—— —— —— various, 268
—— —— purely incandescent, 269
—— —— —— platinum, 271
—— —— —— Bernstein, 294
—— —— —— Cruto, 292
—— —— —— Edison, 272
—— —— —— Lane-Fox (Victoria) 284
—— —— —— Maxim, 287
Glow lamps, purely incandescent, Siemens, 291
—— —— —— Swan, 280
—— —— —— Weston, 288
—— —— —— Woodhouse and Rawson, 290
Glow lamps at Vienna, 297
—— —— general remarks on construction, efficiency, and life of, 301

I.

Installations, 83
—— arc lamp, 91
—— glow lamp, 101

L.

Light, electric, 3

M.

Measurements, electric, 52

O.

Ohmmeter, Ayrton and Perry, 65

P.

Photometric methods, 77
Photometer, Bunsen, 79
—— Selenium, Siemens, 80
—— Dispersion, Ayrton and Perry, 81

S.

Sun lamp, 257

U.

Units, electrical, 11

INDEX OF INVENTORS' NAMES.

A.

Abdank, lamp, 157
Arago, lamp, 162
Archereau, lamp, 166
Aron, electricity meter, 74
Ayrton and Perry, ammeter, 55
—— Ergmeter, 73
—— Ohmmeter, 65
—— Photometer, 81
—— Voltmeter, 57

B.

Ball, dynamo, 51
—— lamp, 162
Bernstein, lamp, 294, 301
Boisseau du Roche, megaloscope, 370
Brush, dynamo, 45, 51
—— lamp, 158, 162, 197, 341
—— current regulator, 98
Bunsen, cell, 23
—— carbons, 148
—— photometer, 79
Bürgin, lamp, 173, 187, 341

C.

Cance, lamp, 157
Carré, carbons, 149
Clerc and Bureau (sun) lamp, 257
Crompton, lamp, 177, 180, 187, 352
Cruto, lamp, 292, 301

D.

Daniell, cell, 20
Debrun, candle, 343
De Changy, lamp, 271
Diehl, lamp, 163

E.

Edison, dynamo, 51
—— current meter, 69
—— lamp, 271, 297, 306, 344
Elphinstone and Vincent, dynamo, 51

F.

Fontaine, lamp, 187
Foucault-Duboscq, lamp, 165

G.

Ganz-Zipernowsky, lamp, 212
—— transformer, 117
Gatehouse, lamp, 297
Gaudoin, carbons, 149
Gaulard and Gibbs, secondary generator, 115
Gérard, lamp, 207
Gramme, dynamo, 45, 51
—— lamp, 158, 189, 341
Gravier, lamp, 157
Greiner & Friedrichs, lamp, 298
Gülcher, lamp, 225

H.

Hefner von Alteneck, lamp, 91
Heinrich, lamp, 247
Hochhausen, dynamo, 51

J.

Jablochkoff, candle, 250, 339
Jaquelain, carbons, 151
Jamin, candle, 254, 343
Jaspar, lamp, 167
Joule, law, 7
Jürgensen, lamp, 170, 341

L.

Lacassagne & Thiers, carbons, 148
Ladiguine (Jablochkoff) lamp, 299
Lalande, ampère meter, 58
Lane-Fox (Victoria), lamp, 284, 299, 344
Lever, lamp, 205

M.

Mangin, projector, 353
Maxim, arc lamp, 341
—— glow lamp, 287, 344
Mersanne, lamp, 209
Müller, lamp, 300

N.

Napoli, carbons, 150

O.

Ohm, law, 7
Opperman, dynamo, 51

P.

Phœnix, dynamo, 51
Piette & Krizik (Pilsen) lamp, 220
Planté, polyscope, 369
Puluj, lamp, 296

R.

Rapieff, lamp, 246
Reynier, lamp, 263
Richter, lamp, 163

S.

Sedlaczek & Wikullil, lamp, 359
Serrin Lontin, lamp, 185
Siemens, dynamo, 38, 51
—— dynamometer, 53
—— galvanometer, 62
—— Selenium Photometer, 80
—— carbons, 148
—— arc lamp, 151, 171, 216, 341
—— glow lamp, 291, 298, 307, 321
Solignaç, lamp, 182
Street & Macquaire, lamp, 228
Swan, lamp, 280, 297, 356.

T.

Tchikoleff, lamp, 224
Thomson-Houston, current regulator, 100
—— lamp, 210
Tommasi, lamp, 268

V.

Van de Poële, lamp, 163

W.

Werdermann, lamp, 266
Weston, current regulator, 100
—— arc lamp, 192, 341
—— glow lamp, 288
—— dynamo, 344
Wheatstone, bridge, 60
Woodhouse & Rawson, lamp, 290, 300

Z.

Zipernowsky, transformer, 117
—— lamp, 212

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